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SMOKE
A STUDY OF TOWN AIR





FIG. 1.—VIEW OF LEEDS, OVERLOOKING KIRKSTALL ROAD.

SMOKE

A STUDY OF TOWN AIR

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PREFACE

THE following pages contain the records of observations which have been carried on at intervals during the last twenty years. In view of the increasing interest taken in the smoke problem in its relation to health, to the growth of vegetation, and to the disintegration of the stonework of ancient buildings, these records, some of which have already appeared in different scientific journals, are now collected together, and published in book form. We have at the same time introduced the experimental results of other observers.

Among the many aspects of the smoke problem which are included in the present inquiry, it will be seen that those only have been studied which afforded a definite and unequivocal result. We have, in consequence, felt ourselves obliged to give the health question a subordinate place. A little reflection will show that however much we may be convinced, or wish to be convinced, of the deleterious effects on health produced by breathing a smoke-laden atmosphere, ordinary medical statistics afford little definite information. It is impossible, in the majority of cases, to point with any certainty to specific cases of disease or mortality as due to this cause, or even mainly to this cause, unless it be during the occasional occurrence of dense fog. The only statistics known to us which bear definitely on the subject are those collected by Dr. Ascher, medical officer of Hamm, Westphalia, which have been contributed to this volume at our request, and for which we offer him our grateful thanks. They will be found in Appendix A, p. 72.

By avoiding unnecessary scientific detail, the material is presented in a manner which, it is hoped, may be readily understood by the non-scientific reader.

J. B. COHEN.

A. G. RUSTON.

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FRONTISPIECE. A view of Leeds, overlooking Kirkstall Road.

“There was a time, both in England and on the Continent, when smoke was considered a necessary evil which had to be suffered. After a while smoke began to be looked upon as a nuisance, and war was declared against it by those who suffered from its disagreeable properties; but now we know that smoke is a waste, and that nobody has better cause to wage war against it than he who produces it. . . . Smoking chimneys are thieves, and their misdeeds should not rise unavenged to Heaven. . . . It is, perhaps, not too much to say that the saving of national wealth effected by regenerative gas heating may amount to a sum sufficient to pay the aggregate national debts of all the civilised nations.”

O. N. WITT.

Address to the Seventh International Congress of Applied Chemistry, held in London, May 31, 1909.

S M O K E

A STUDY OF TOWN AIR

INTRODUCTION

THE subject of the emission of coal smoke from chimneys is one which has for many years past forced itself with increasing prominence upon the notice of those residing in the larger towns.

It is admittedly its æsthetic rather than its economic aspect which has appealed, in the first instance, to popular sentiment. Blackened buildings, darkened skies, and the general air of dirt and gloom which are typical of an English industrial centre have aroused a growing feeling of dissatisfaction among a certain section of the community, and have led to the formation here and there of societies for the prevention of smoke. Some of these societies have pursued their object with praiseworthy energy. By means of pamphlets, public addresses, conferences and exhibitions of smoke-preventing appliances they have sought to enlist public sympathy. They have pointed to the loss of fuel which coal smoke entails, to the physical deterioration and lowered vitality of the inhabitants of towns caused by inhaling a contaminated atmosphere, to the loss of daylight, and to the destruction of vegetation.

It is a remarkable fact, nevertheless, that in face of the active propaganda of these societies, and a very widespread sympathy with their aims, as well as the existence of certain repressive legislative measures directed against the smoke of factories, placed in the hands of the local authority, the emission of smoke continues with almost unabated vigour from both house and factory chimneys.

It might be interesting to inquire into the cause of this

general apathy, and of the practical failure of local control. It is in reality not difficult to explain.

In the first place, there is the inertia of established custom which resists any change, especially in domestic organisation.

Assuming the existence of an effective system of burning fuel without smoke both for domestic and factory purposes, it would be difficult to persuade manufacturers or householders to adopt it unless it offered a substantial monetary saving more than sufficient to cover the initial outlay. In the second place, private and commercial interests dominate to a large extent our civic life. The authorities are rightly unwilling to interfere with the business of the manufacturer, or with the liberty of the private citizen, excepting in matters seriously affecting the public weal. It is useless to appeal to them on the ground that coal smoke is unsightly, or in a vague sort of way that it lowers vitality, or destroys vegetation. *Æsthetic* considerations possess little weight with the Legislature, and the effect of smoke on health must be very clearly proved before action is taken. Thus, no President of the Local Government Board has yet ventured to pledge himself to any definite policy for meeting the evil of smoke by more effective means than our present system affords, however inadequate that may be. Not even the enormous aggregate loss of fuel, amounting to nearly two and a half million tons, which passes into the air as smoke, disturbs him (see p. 11). That is the private concern of the householder and manufacturer. Thus matters are at a standstill. But if it can be shown beyond any question that the effects of smoke are distinctly injurious to health, or clearly pernicious in other ways, and that its removal can be effected without serious expense or discomfort, then the authorities have not only the right, but a positive duty to interfere and enforce more drastic means for its suppression. The question, then, arises: have we any trustworthy information on the subject? What is the nature of soot? What is the quantity emitted from domestic and from factory chimneys, and what is the quantity temporarily and permanently deposited? What is the quantity suspended in the air, and to what extent does it affect health? Does it corrode as well as discolour masonry, brickwork, and metal-work, and how far is it destructive to vegetation? Do its effects extend beyond the immediate vicinity of the town; to

what extent does it shut out daylight, induce or aggravate fog, and, finally, what is the increased cost of cleaning?

It is to some of these questions that we have been trying to obtain definite answers. We have not entered at all into the subject of the cause and cure for smoke which have been very thoroughly examined and discussed by other writers. Our attention has been directed to collecting together data on the imperfect combustion of coal, and presenting an accurate picture of the results.

It is hoped that these facts will enable smoke abatement societies and others who are interested in the suppression of smoke to appeal with additional force and greater success than has hitherto attended their efforts to the central authority as well as to the general public.

THE SOLID PRODUCTS OF COMBUSTION

1. The Composition of Soot

A VERY important—perhaps the most important—feature of the smoke problem lies in the nature of soot. Soot consists mainly of carbon, tar, and ash (mineral matter), together with small quantities of sulphur, arsenic, and nitrogen compounds, and frequently possesses an acid character. If it were entirely composed of carbon and mineral matter it would be rapidly removed by the first heavy rainfall, and there would probably be no steady accumulation of grime on brickwork, masonry, and vegetation, such as strikes the eye on entering a large manufacturing town. But the tar which soot contains causes it to adhere like a varnish, even to the polished surface of glass from which a current of water will not detach it.

The analyses of soot which have been made from time to time by different experimenters show great variations in composition.¹ When one considers the very different conditions under which coal is burnt in the factory and the home it is obvious that the character of the soot must vary. For soot is a product of incomplete combustion, and is formed partly by the mechanical removal of dust by the chimney draught, and partly by the decomposition of the fuel such as occurs in the process of destructive distillation. It might, therefore, be expected that the higher temperature and stronger draught of a factory furnace would produce a soot more by mechanical removal and less by incomplete combustion than

¹ W. C. Roberts-Austen, *Report on the London Smoke Abatement Exhibition*, p. 9; *Report of the Manchester Air Analysis Committee* (1891), p. 7; Cohen and Hefford, *Journ. Soc. Chem. Ind.* (1893), 12. 4; W. Irwin, *Journ. Soc. Chem. Ind.* (1902), 21. 533; E. Knecht, *Mem. Manchester Lit. and Phil. Soc.* (1905), 49. 11; R. H. Clayton, *Journ. of Gas Lighting* (1907), 100. 427.

a domestic grate, in other words, a soot containing more ash and less tar.

Not only is this the case but the character of the soot varies with the distance from the grate at which it has been deposited.

The analyses given below illustrate these facts very clearly.

The method of analysis was to extract the dried soot with ether to remove the tar (which was then estimated by distilling off the ether) and to burn the residue in a current of oxygen by the ordinary process.¹

The first table gives the analyses of soot from domestic fireplaces. The composition of the coal used is given in the second column, the composition of the soot from the kitchen flue in the third, and that at the bottom and top of the dining-room flue in the fourth and fifth columns.

Analyses of Domestic Soot from Winston Gardens, Headingley.

Constituents.	Original Coal.	Kitchen Flue.	Dining Room Flue	
			bottom 5 feet from grate.	top 33 feet from grate.
Carbon	76.80	52.34	36.45	37.22
Hydrogen	4.90	3.68	3.51	3.51
Tar	0.88	12.46	34.87	40.38
Ash	1.80	17.80	5.09	4.94

It will be seen how the higher temperature of the kitchen fire and stronger draught increase the amount of ash and decrease that of the tar when compared with the dining-room sample.

The same result is given in another experiment carried out with soot from another house burning a different quality of coal, though the difference between kitchen and study flue is not so marked.

Analyses of Domestic Soot from North Grange Mount, Headingley.

Constituents.	Original Coal.	Kitchen Flue.	Study Flue.
Carbon	76.47	45.91	47.15
Hydrogen	5.22	2.18	4.85
Tar	0.92	10.20	15.68
Ash	2.10	27.34	20.22

The following analyses are of soot from coal burnt in an

¹ The complete analyses and detailed description of the process are given in Appendix B, p. 77.

ordinary grate and under a boiler attached to a chimney about 110 ft. high.

Analyses of Soot from the University, Leeds.

Constituents.	Original Coal.	Ordinary Grate Fuel	Boiler Chimney.			
			Bottom.	13 feet from base.	70 feet from base.	Top of Chimney 110 feet.
Carbon . . .	69.30	40.50	19.24	16.66	21.80	27.00
Hydrogen . .	4.89	4.37	2.71	0.86	1.44	1.68
Tar	1.64	25.91	0.09	0.28	0.80	1.14
Ash	8.48	18.16	73.37	75.04	66.04	61.80

These analyses emphasize what was stated above as to the large increase in ash and decrease in tar in the boiler chimney. The last set of analyses are of soot taken from the bottom and top of the chimney of a brass foundry in Leeds burning liquid fuel.

Analyses of Soot from a Brass Foundry, Leeds.

Constituents.	Bottom of Chimney.	Top of Chimney.
Carbon	11.36	47.71
Hydrogen . . .	1.03	2.35
Tar	1.02	10.62
Ash	82.16	31.42

This analysis shows a much larger quantity of tar in the soot from the top of the chimney than the previous one and affords a good illustration of the enormous variation in the composition of soot from different fuels burnt under different conditions.

In connection with the subject of the proportion of tar in soot,¹ reference should be made to the table on p. 16, giving the analyses of the suspended matter carried down by rain-water in different parts of Leeds. It will be seen that the proportion of tar is larger in the residential than in the industrial quarters of the city, and varying from about 4.5 per cent. at Hunslet, the centre of a large industrial area, to over 15 per cent. at Roundhay on the outskirts of the city.

¹ Monthly Weather Report of the Meteorological Office for April, 1895, p. 9.

2. The Acidity of Soot

An important feature of soot is its liability to contain acid.

Dr. Russell found no acid in rain-water (p. 36) unless soot was present, and he was able to wash out the acid from soot with water and estimate its amount by titrating with decinormal alkali. The amount of free acid in 9 samples calculated as percentage of sulphuric acid was as follows:—

1.4, 0.5, 7.2, 0.0, 0.0, 4.9, 0.8, 1.2, 2.3.

Dr. Russell remarks that “if the soot in the London air be generally acid its adherence to bodies and subsequent moistening by rain will tend to corrode those bodies, and as the surface becomes roughened so will the soot more readily and more firmly adhere and the disintegrating action will proceed with increased rapidity.”

Our own experiments performed in the same manner and calculated as sulphuric acid have given similar results (see also p. 38). The original coal, it may be added, was entirely free from acid.

Percentage of Free Acid Calculated as Sulphuric Acid in Soot.

Source of Sample.	Base of Chimney.	Top of Chimney.
Soot from brass foundry . . .	0.0	0.65
North Grange Mount study flue .	0.50	—
kitchen flue .	0.0	—
The "University" fire-place . . .	0.37	—
boiler	1.62	0.56
Winston Gardens dining-room . .	0.92	0.92
" " kitchen	0.28	—

3. The Amount of Soot emitted from Chimneys

Of the actual amount of soot emitted from factory chimneys it is clearly impossible to obtain trustworthy data. It will vary with the quality of coal, the size and structure of the chimney and the method of firing. Estimates have been made by different observers of the amount of coal which escapes combustion; but the experiments, though numerous, are not of a very concordant character.

In 1855 Delejeune¹ determined the unconsumed carbon to

¹ *Bull. de la Soc. d'Encouragement* (1855), p. 473.

be 5 per cent. of the total weight. In 1858 John Graham¹ stated, from the result of his observations, that very black smoke does not contain more than 0.1 per cent. of the carbon burnt. Scheurer-Kestner,² in a very careful and elaborate research on flue gases from boiler furnaces, found that the carbon lost as fuel never exceeds 1 per cent., while on the average it is 0.5-0.75 per cent. A case, however, is recorded in which a coal containing 69 per cent. of carbon lost 2.03 per cent. of the fuel as soot. In the matter of house fires we have a large mass of trustworthy data in the analyses of the late Sir W. Roberts-Austen, undertaken in connection with the London Smoke Abatement Exhibition.³ The flue gases were aspirated through a metal tube loosely packed with asbestos, then through tubes of calcium chloride to absorb water, and finally through tubes of soda-lime to absorb carbon dioxide. The aspiration was continued for 3 hours from the first lighting of the fire and the average volume of gas drawn through the tubes was 14 litres, rather more than $\frac{1}{1000000}$ of that passing through the flue. On the average of 40 experiments with different kinds of grates, but burning for the most part the same fuel (Wallsend), 0.0532 grains of soot were collected during an average consumption of 12 lbs. of coal. The weight of soot collected \times the volume of gas passing up the flue = 5320 grains, that is, the weight of soot from 12 lbs. of coal, or rather over 6 per cent. Although this result can only be regarded as a rough estimate, it shows a remarkable agreement with our own observations which were carried out with the main object of estimating the soot carried up the chimney.⁴ The average per cent. of soot passing up the chimney in 12 analyses, including 8 of Yorkshire coals, 2 of Durham coals, and 2 of Wigan coals, amounted to 6.5 per cent. on the carbon burnt. The quantity of soot obtained in different experiments with the same kind of coal varies as will be seen from the table, p. 10. It is no doubt influenced by the manner

¹ *Mem. Lit. and Phil. Soc. Manchester* (1860).

² *Mémoires extraits du Bull. de la Soc. Ind. de Mulhouse*, Laacroix, Paris (1875), and "Recherches sur les produits gazeux de la combustion de la houille," *Ann. Chem. Phys.* (1870), **20**. 66.

³ *Report on the London Smoke Abatement Exhibition of 1884*.

⁴ Cohen and Hefford, "Combustion of Coal in House Fires," *Soc. Chem. Ind.* (1893), **12**. 121; Cohen and Russell, *Soc. Chem. Ind.* (1896), **15**. 86.

of firing and by the amount of draught. There was no slack in any of the samples.

The determinations were carried out as follows:—

The chimney gases were aspirated through a brass tube of about half-inch diameter. The end inserted into the chimney was closed, and a narrow slit about 3 inches long was cut longitudinally at about 1 inch from the closed end, through which the chimney gases could be drawn. To the open end of the brass tube, a glass tube containing the weighed cotton-wool plug was inserted.

The cotton plug was dried in a weighing bottle in the steam oven, then kept overnight in a desiccator over sulphuric acid, and weighed against another cotton plug dried in the same manner along with the experimental one, and the process repeated until consecutive weighings were constant.

The air was aspirated by means of two gas-holders, each holding about 15 litres, and the chimney gases were drawn off at the rate of about a litre a minute, which would approach the speed of the gases passing up the flue. The object of this was to prevent a greater deposition of soot in the brass tube than would occur in its progress up the chimney. Before reaching the aspirator a portion of the chimney gases was tapped by a smaller aspirator and made to pass through a drying tube and two weighed potash apparatuses. An average sample of chimney gases was thus obtained in which the CO_2 was determined.

In this way the operation was continued for about five to six hours, and during the time 200–300 litres of chimney gases were aspirated by the large aspirator, of which 5–20 litres were drawn through the small one. A good fire was maintained all the time, and the gases were aspirated from the first lighting of the fire.

A tabulated statement of the results is given on the next page.

In column 4, the carbon in the carbon dioxide of the air, calculated at 0.04 per cent. and measured at 20° , is deducted.

This quantity, 6.5 per cent., seems a very high figure, representing an annual loss of more than 2 million tons on the estimated domestic consumption of 32 million tons for the United Kingdom. It is a significant fact that Sir W. Roberts-Austen found that in one case as much as 2.25 per cent. of soot on the

No.	Carbon Dioxide.			Soot.		Per cent. of Soot on C. burnt.	Name of Coal.
	Chimney Gases.	Weight of CO ₂	Weight of C	Chimney Gases.	Weight of Soot.		
	Litres.			Litres.			
1	10.0	0.045	0.0102	218.0	0.0155	6.9	"Silkstone Hards" (Yorks).
2	10.5	0.0435	0.0097	282.5	0.0207	10.2	
3	9.5	0.037	0.0082	249.5	0.0174	8.0	
4	7.0	0.0485	0.0118	231.0	0.0238	5.8	
5	7.5	0.058	0.0143	164.5	0.0292	9.3	
6	7.5	0.060	0.0148	182.5	0.0219	6.0	"Haigh Moor Best" (Yorks). "Harvey Seam" } (Durham). "Hutton Seam" } "Best Deep Yard" } (Lancs.). "Best Arley" }
7	5.0	0.037	0.0091	175.0	0.0247	7.7	
8	6.5	0.0515	0.0127	278.5	0.0278	5.1	
9	16.0	0.118	0.0289	240.0	0.0243	5.6	
10	6.5	0.053	0.0131	230.5	0.0227	4.8	
11	6.0	0.0375	0.0090	262.0	0.0282	7.1	Mean.
12	6.0	0.0475	0.0118	230.0	0.0232	5.1	
Total	98.0	0.6365	0.1536	2744.0	0.2844	6.5	

fuel burnt was deposited in the flue itself of an ordinary fire-place, whilst in another case 0·61 per cent. collected in the flue, consisting of a sheet-iron pipe only 6 feet long. The loss estimated by R. H. Clayton¹ at 50 per cent. on the coal burnt is, of course, absurd, and is apparently a mere guess unsupported by experiments.

If, then, we take 6 per cent. as the minimum loss on the domestic coal consumption (32 million tons), and 0·5 per cent. as that on factory consumption (100 million tons), we get for the whole country a loss in the form of soot of—

	Tons.
Domestic	1,920,000
Factory	500,000
Total	2,420,000

These figures do not, of course, imply the saving which might be effected by the more efficient utilization of the calorific value of the fuel, which, according to Mr. Beilby, amounts to something like 20 times this figure estimated as coal.²

The fact that gas-heating is proving more economical, convenient, and efficient for many industrial processes, and is being largely adopted by the more enterprising manufacturing firms, seems to point to a time, perhaps not far distant, when factory smoke will only form an insignificant portion of the whole amount of the products of combustion.

4. The Amount of Solid Impurities in the Air

The first accurate observations on the quantity of suspended organic matter in the air were made by the late Dr. W. J. Russell on London air.³ He caused air, at the rate of 250 cubic feet an hour, to be pumped through a long tube plugged with clean glass wool, which was then ignited with copper oxide, and the amount of carbon and nitrogen estimated. He found for fine, dull, and foggy weather (not dense fog) the following average amounts of organic matter (carbon + nitrogen) in 100 cubic feet.

¹ *Journ. of Gas Lighting* (1907), **100**. 427.

² These figures are taken from the *Final Report of the Royal Commission on Coal Supplies* (1905), Vol. III. p. 11.

³ "On the Impurities in London Air," *The Monthly Weather Report of the Meteorological Office*, August, 1885.

	M. grams in 100 cub. ft. of air.
Fine weather	0.35
Dull „	1.03
Foggy „	2.44

Similar experiments on the amount of suspended impurities were carried out in 1897 at the Philosophical Hall, Leeds, near the centre of the town (station 4 on the map, p. 15).

The air was aspirated through an aperture in a window 15 feet above the ground, overlooking a side street where there was no heavy traffic. The apparatus used for estimating the amount of suspended matter is shown in Fig. 2.

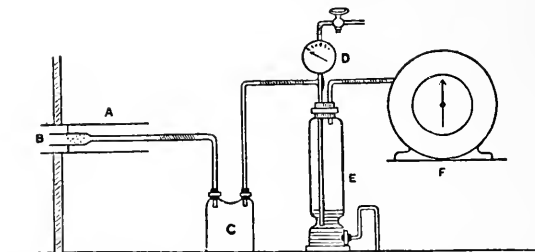


FIG. 2.—Apparatus for estimating suspended matter in air.

It consists of a leaden tube, A, fixed through the window, in which an open glass tube, B, is held in position by a cork diaphragm. The wide portion of the glass tube contains a weighed cotton-wool plug, and the narrow end is connected with an empty bottle, C, and a Desaga water-jet aspirator, which is attached to a large wash tower, E, so that air can be aspirated through B and C, and delivered to the experimental gas meter for measurement. The air was aspirated for about 6 hours daily during May and June, 1897, at the rate of 25 to 35 cubic feet a day.¹ The plug was weighed at intervals. Two sets of experiments were conducted alternately, and the aggregate increase in weight is as follows:—

No. of experiment.	Cub. ft. aspirated.	Gain in weight m. grams.	Weight per 100 cub. ft. m. grams.
1	436.94	5.2	1.19
2	681.75	8.1	1.20

These figures concord very well with Dr. Russell's results for dull weather.

¹ Full details of the method are given in the *Journ. Soc. Chem. Ind.* (1897), 16. 411.

From this we may conclude that the weight of solid matter in the air of Leeds is 1.2 milligrams per 100 cubic feet, and as the solid matter collected on the plugs was quite black, it may be assumed that it consisted mainly of soot. Supposing this amount to be uniformly distributed through the atmosphere to a height of 300 feet before being dispersed, it will represent a weight of 2 cwt. of solid matter suspended continuously above an area of 1 square mile. If, as has been estimated, the atmosphere is renewed 50 times in 12 hours, the quantity of soot discharged into the air during this period will amount to 5 tons on the square mile. If this quantity of 5 tons is calculated for the 16 square miles covered by the city, it amounts to 80 tons. This figure is rather lower than that ascertained in other ways (see p. 20), but it must be remembered that the estimate is only a rough approximation. A portion of this soot is constantly falling, whilst the greater part is blown away.

5. The Daily Soot-fall

Delejeune,¹ in 1855, stated that $6\frac{1}{3}$ tons of soot fell in 12 hours in the town of Lille from a calculated loss of 5 per cent. on all the fuel burnt, a number which is probably over the mark. From the quantity contained in snow which fell in the winter of 1902, Mr. W. Irwin² estimated roughly that 30 tons of soot fell on 100 square miles with Manchester as centre. Mr. F. W. Harris,³ of Glasgow, from experiments with soot-collecting boxes placed in different parts of the city during the four winter months, calculated that 45 tons of soot fell each day upon Glasgow's area of 12,796 acres, or at the rate of 16,410 tons per annum, or 820 tons per square mile per annum. This is much above our estimate for Leeds, which was found to be only 220 tons per square mile per annum, or of Messrs. Des Vœux' and Owens'⁴ figure for London, which was about 259 tons on the average of the four stations investigated (see p. 84).

A fairly accurate idea of the amount of soot falling in Leeds has been arrived at in two ways, namely, by estimating

¹ *Bull. de la Soc. d'Encouragement* (1855), p. 473.

² *Journ. Soc. Chem. Ind.* (1902), **21**, 533.

³ "Glasgow's Smoke Nuisance," by P. Fyfe, *Glasgow Herald*, Oct. 16, 1909.

⁴ "The Soot-fall of London," *The Lancet*, Jan. 6, 1912.

the solid impurities deposited on snow and by determining the amount of solid matter carried down by rain. In January, 1892, after a fall of snow which lay on the ground for several consecutive days during clear and frosty weather, a sample covering 1 square yard was carefully removed from a grave-stone in the parish churchyard (between stations 2 and 4, see map, p. 15) a short time after the fall had ceased. The snow was melted, filtered, and the solid estimated. Fresh samples were taken and analysed on the three following days. They contained soot in suspension, and ammonium sulphate, and chloride, calcium sulphate, and free sulphuric acid in solution. The appearance of the samples is shown in Fig. 3, taken from



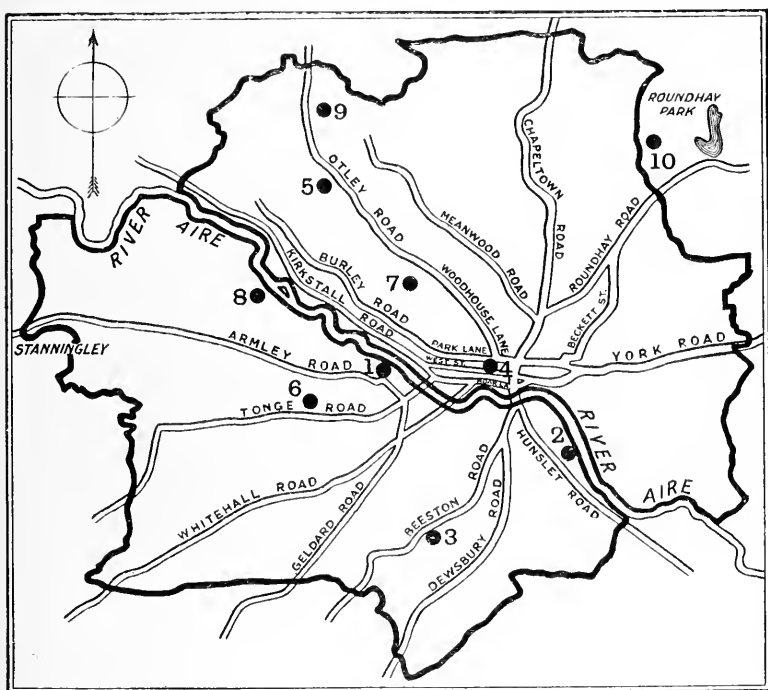
FIG. 3.—Melted snow collected on four successive days.

a photograph. The bottle on the left representing the first day's snowfall was translucent, whilst the last of the four was quite opaque.

The weight of solid matter carried down, as determined from the first sample, was equivalent to 16 cwt. to the square mile, whilst the additional weight of soot which accumulated on each successive day was equivalent to 4 cwt. to the square mile.

By a periodical examination of the rain-water (which carries down both soluble and insoluble impurities) derived from different localities, a fair notion of the relative quantity of these impurities has been ascertained. Ten representative stations were selected in Leeds of different types, varying from

industrial to suburban, and also one at Garforth, situated about 7 miles east of Leeds in an agricultural district. The accompanying plan (Fig. 4) indicates the situation of the different stations (with the exception of Garforth), and the character of the area in which they were located. The rain was collected by funnels



- | | | | |
|-----------------------|-----------------------|---------------|------------------------|
| 1. Leeds Forge | } Industrial Centres. | 5. Headingley | } Residential Centres. |
| 2. Hunslet | | 6. Armley | |
| 3. Beeston Hill | 7. Woodhouse Moor | | |
| 4. Philosophical Hall | 8. Kirkstall | | |
| | 9. Weetwood Lane | | |
| | | 10. Roundhay | |

FIG. 4.—Sketch-map of Leeds and its environs.

12 inches in diameter, fitting into the necks of glass bottles, which were emptied monthly, and the contents analysed. The results of the experiments, which were continued for 12 months from November, 1907, to October, 1908, are contained in the following table. The table gives only the suspended matter; the soluble impurities are discussed later (p. 38).

Solid Impurities in Leeds Rain.

Tons per square mile per annum.

	Station.	Suspended matter.			
		Carbon.	Tar.	Ash.	Total.
1	Industrial { Leeds Forge . . .	189.6	31.4	318.0	539.0
2		241.2	19.7	187.2	448.1
3		87.1	42.6	202.5	332.2
4	Town Philosophical Hall	99.7	22.3	120.6	242.6
5	Residential { Headingley . . .	100.2	12.3	56.9	169.4
6		98.0	9.7	61.7	169.4
7		63.2	9.1	41.7	114.0
8		52.3	8.0	40.3	100.6
9		19.2	7.4	15.4	42.0
10		7.7	4.0	14.0	25.7
11	Garforth . . .	—	—	—	—

The industrial area of Leeds lies almost entirely in the southern half of the city. To the north and east the city merges into purely agricultural country. These facts explain the rapid diminution in the solid impurities on passing northwards from the centre of the town. Taking the centre as the unit, 1 mile out they fall to $\frac{1}{2}$, and $2\frac{1}{2}$ miles out they fall to $\frac{1}{6}$, whilst at Roundhay, about 3 miles north-east of the centre, the impurities are $\frac{1}{20}$ of those in the industrial areas. The waste of fuel in the form of unburnt coal is illustrated here in a very striking way; for in Hunslet there is each year a deposit of nearly 450 tons per square mile, whilst the average amount for the whole area included in the investigation, roughly 16 square miles or 4 miles square, amounts to 220 tons per square mile per annum, or an average of over 15 cwt. per square mile a day for the whole town.¹ Taking the average of 5 stations included in the 4 square mile central area we have an average of 335 tons per annum, or roughly 1 ton per square mile a day.²

¹ Delejeune in 1855 estimated roughly that $6\frac{1}{2}$ tons of soot fell in 12 hours in the town of Lille, a number which was probably over the mark, whereas W. Irwin (*Journ. Soc. Chem. Ind.* (1902), 21. 533) estimated roughly that 30 tons fell on 100 square miles, with Manchester as centre, or 5 tons to 16 square miles.

² It will be noticed that the amount of deposit on the snow on successive days is about one-fifth of that carried down by rain, or one-fourth of that

The diagram of Fig. 5 represents by the length of the vertical columns the proportion of carbon tar and ash in the soot from the rain of the various stations numbered on the horizontal line.

6. Soot-tar, its Amount and its Effects

Soot, as we have seen (p. 5) is not pure carbon; but contains varying amounts of tar. This tar adheres so tenaciously to everything that it is not even removed by rain. It is, in short, a kind of varnish. In order to ascertain the amount of this sticky material glass plates 1 foot square were exposed horizontally at three stations, one in a garden at Pool (9 miles N.W. of Leeds), one on the roof of the University buildings (near station 7 on the map, p. 15), and one on the Philosophical Hall (station 4). These were disposed so as to be as far as possible from chimneys. The deposit on these plates after an exposure of a few weeks, loose matter having been removed by running water, was analysed and weighed. Fresh plates were then put in the place of those removed, and the process repeated from month to month. The deposit contained about 50 per cent. of carbon, and was therefore mainly soot. The proportion at the three stations was as follows: for 1 part deposited at station 4 near the centre of the town, $\frac{1}{10}$ was deposited at the University, and $\frac{1}{20}$ at Pool. The photograph (Fig. 6) shows the difference between the town and the country plate after an exposure of 6 months.¹

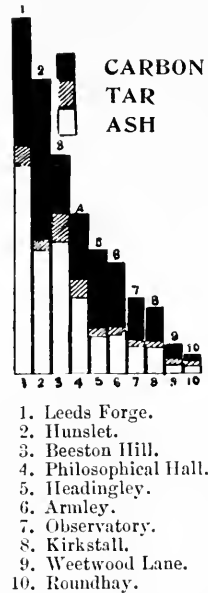


FIG. 5. — Relative proportion of suspended matter.

carried down by falling snow. It is obvious that a much smaller quantity will be deposited by gravitation in a dry atmosphere than when the atmosphere is washed by rain or snow, and that the rain will cleanse more effectively than the snow (see Appendix B., p. 77).

¹ This method may be recommended for testing the condition of the atmosphere. The plates after exposure for a certain time should be compared with plates of standard tints.

These experiments have been repeated recently at a larger number of stations with the following results:—

	Station.	March 23— June 23, 1910, m. grms.	June 23— Sept. 23, 1910, m. grms.	Cwts. per sq. mile per annum, total.
2.	Hunslet	52·6	46·5	110
1-4.	Kirkstall Road (be- tween 1 and 4) .	26·2	31·1	64
4.	Philosophical Hall .	26·4	30·4	63
5.	Headingley	11·3	17·2	27
7.	Observatory (Wood- house Moor) . . .	15·4	9·0	32
10.	Roundhay	1·9	2·1	4·5

It will be seen that the ratio of the deposit at Roundhay to that at Hunslet is almost exactly 1 to 24, which was the ratio obtained in the previous set of experiments for town and country, and approximates to that of the total suspended matter, namely, 1 to 17 in the two localities.



FIG. 6.—Town and country plate after 6 months' exposure.

Assuming that 5000 tons¹ is the daily, or 1,500,000 tons is the annual coal consumption in Leeds over an area of 16 square miles, and that $\frac{1}{3}$ is burnt in house fires emitting 6 per cent. of soot, and $\frac{2}{3}$ in factories giving off 0·5 per cent. of soot, we may determine the fate of the unburnt fuel as follows: ²—

¹ This figure is taken from the ratio of coal consumption to population as ascertained for London. No other estimate seems available.

² The permanent and temporary deposits are calculated on the average of the 5 stations in the 16-mile area covered by the town.

Destination of Soot emitted in Leeds.

(Tons per annum.)

Total emitted from factories	5,000
„ „ house fires	30,000
	<hr/>
	35,000
	<hr/>
Soot blown away	31,480
„ deposited temporarily	3,472
„ „ permanently	48
	<hr/>
	35,000
	<hr/>

The amount which escapes is nearly 10 times that which falls, and more than 600 times that which remains as a permanent stain.

The opinion has been expressed¹ that owing to the larger percentage of tar in domestic soot and consequently its greater adhesive property, the blackening of buildings and vegetation is mainly due to the domestic fire-place. There is undoubtedly much truth in this assertion; for if we multiply the amount of soot from residential and industrial centres by their relative content of tar we find that the industrial tar deposit is nearly equal to that of the domestic product. So that, assuming the ratio of total deposit of the industrial and residential centres to be 400 to 25, and that of the tar content in the two cases to be 2 to 30, we get $400 \times 2 = 800$ as against $25 \times 30 = 750$, which is slightly in favour of the suburban area. We must remember, however, that the industrial deposit includes soot from masses of workmen's cottages which cluster round the factories and help to raise the percentage of tar. This is shown by the amount of tar in the three industrial centres of Leeds, which varies from 4·5 to 13 per cent., and is much in excess of that obtained directly from the factory chimney. Mr. Harris of Glasgow estimated, from the amount of tar found in the gases from domestic chimneys, that in the city of Glasgow 25·7 tons of tarry matter are delivered into the air every day. Our own observations on the amount of tar in soot and the quantity emitted in Leeds confirm this result. Thus, estimating as before that on 5000 tons of coal consumed daily in Leeds, $\frac{1}{3}$ is

¹ R. H. Clayton, *Journ. of Gas Lighting* (1907), 100. 427.

domestic and $\frac{2}{3}$ factory (taking the ratio for the whole country) and reckoning 6 per cent. loss on the domestic and 0·5 per cent. on factory consumption, there is a total loss of 117 tons daily, which, taking 20 per cent. as the content of tar, gives 23 tons of tar emitted daily. It must, of course, be remembered that Glasgow's consumption of coal is probably much higher than that of Leeds.

7. Effects of Soot on Vegetation

Soot may exert a detrimental effect on the growth of plants in three ways, namely, by blocking up the stomata and thus



FIG. 7.—Holly leaf, half cleaned.



FIG. 8.—Laurel leaf, half cleaned.

impeding the process of transpiration; by coating the leaf and so reducing the intensity of sunlight, and at the same time affecting the assimilation of carbon dioxide, and lastly by the corrosive effect of the acid it contains. In both cases the tarry deposit plays an important part. The photographs of Figs. 7 and 8 are taken from a holly and a laurel leaf growing in the grounds of the University. From the one half of each leaf

the soot has been removed and the green colour then bleached, whilst the soot remained intact on the other half of the leaf.

Leaves, especially evergreens, are thus coated with a black adhesive deposit which not only absorbs the light and so arrests assimilation, but has a much more serious effect in permanently blocking up the stomata. Although the stomata are more numerous on the underside of the leaf whilst the soot tends to attach itself to the upper surface, nevertheless, an examination

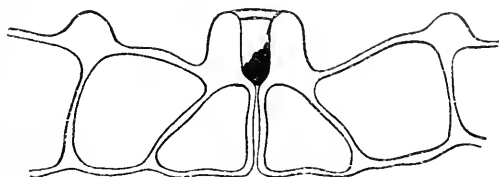


FIG. 9.—Stoma of juniper.

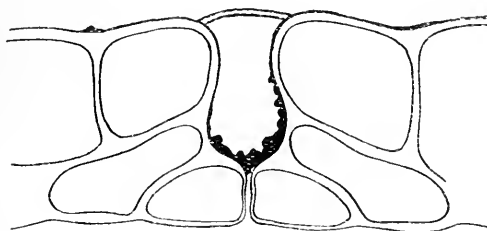


FIG. 10.—Stoma of silver fir.

of the leaves of different plants has shown that those on the lower surface are also affected. The conifers appear to be the most sensitive of all plants to the influence of smoke, and their characteristic sunk stomata, which serve the purpose of minimising transpiration, form very efficient traps for particles of soot. The only two localities in Leeds where conifers attain even moderate growth are around the two outlying stations 9 and 10 (see p. 15). The diagrams (Figs. 9 and 10) are magnified sections through the leaf of a juniper and silver fir.

8. Assimilation by Leaves of Evergreens

The classical researches of Blackman and Horace Brown¹ have proved conclusively that the main factors influencing carbon dioxide assimilation are—

- a. The number and position of the stomata.
- b. The intensity of the light.
- c. The temperature of the leaf.
- d. The carbon dioxide content of the surrounding air.

Thus Blackman shows that it is by means of the stomatal openings that the gaseous interchanges in the leaf take place, and that if the leaf has its stomata only on the upper or lower surface, the assimilation of carbon dioxide only takes place on that side of the leaf possessing stomata. If, on the other hand, the leaf possesses stomata on both upper and lower surfaces, the carbon dioxide absorbed follows very closely the ratio of distribution of the stomata.

In the same paper he also shows that if the surface of the leaf possessing stomata be coated over with a thin layer of vaseline, thus blocking the openings, the carbon dioxide absorption is practically stopped. He has also shown that up to a temperature of about 35° there is a steady and increasing rise of assimilation, as seen from the following numbers:—

Temperature.	Grams of CO ₂ per 50 sq. cm. assimilated per hour.
10°	0·0041
20°	0·0085
30°	0·0151
35°	0·0205

Brown and Escombe have found that other factors being constant, the carbon dioxide assimilation is proportional to the percentage of carbon dioxide in the surrounding air.

In the atmosphere of industrial districts all these factors come into play. The coating of the leaves with a tarry deposit will act like vaseline—block up the stomata and check, if not prevent, assimilation. The smoke-cloud will lower the intensity of the light, and, by cutting off direct radiation, tend to lower the temperature, thus still further retarding assimilation. On the other hand, the slightly increased carbon dioxide content of the air of towns will tend to increase the rate of assimilation.

¹ *Phil. Trans.* (1895), p. 502; *Proc. Roy. Soc.* (1902), p. 397; *Proc. Roy. Soc.* (1905), p. 402.

We have no available figures of the content of carbon dioxide in the air in different parts of Leeds, but we have numerous analyses of the air of Manchester, London, Sheffield, and elsewhere, which enable us to estimate the variation in carbon dioxide.

Air in different Localities.

(Vols. of CO₂ per 10,000 vols. of Air.)

Locality.	Manchester.	London.	London.	Sheffield	Scotch Hills.	Over Sea.
	(Angus Smith.)	(Russell.)	(Angus Smith.)	(Williams.)	(Angus Smith.)	(Thorpe.)
Town . .	4.03	4.03	4.39	3.85	—	—
Suburbs .	—	—	3.01	3.26	—	—
Country .	—	—	—	—	3.36	3.01

The difference is not great, amounting to about 1 part in 10,000, between the best and worst specimens of air. This difference will scarcely affect the plant when labouring under adverse conditions, and any advantage gained by the slightly increased carbon dioxide content is more than overbalanced by the disadvantages produced by the presence of other impurities.

A comparison¹ has been made of the rate of assimilation of carbon dioxide by laurel leaves from different parts of Leeds, the results of which are summarized in the following table:—

Assimilation of CO₂ by Laurel Leaves.

Expt. No.	Source of Leaves.	Area of Leaves.	Intensity of Light.	Hourly mean temperature.	Total CO ₂ assimilated.	CO ₂ assimilated per 10 sq. inches per 10 hours.
	Station.	Sq. ins.	C.c. N/10 Iodine.	C.	Milligrams.	Milligrams.
1	9	36.21	1.22	10.8	21.56	5.95
2	9	23.5	3.4	17.6	40.48	17.2
3	9	23.52	1.9	13.7	36.08	11.51
	9	29.84	1.9	13.7	37.64	11.82
4	9	29.84	1.78	18.0	38.72	12.09
	5	24.35	1.78	18.0	16.72	6.86
5	9	29.84	2.12	12.6	34.32	11.50
	7	12.54	2.12	12.6	6.04	4.81
6	9	29.84	0.46	14.8	29.04	9.73
	1-7 ²	15.62	0.46	14.8	2.20	1.48
7	9	28.64	2.8	17.6	47.21	13.52
	4	16.42	2.8	17.6	2.64	1.56

¹ Crowther and Ruston, *Journ. Agric. Science* (1911), 4. 25.

² From a garden midway between stations 1 and 7.

The experiments were conducted as follows: three leaves of the current season's growth were placed in a flat wooden box with glass sides (Fig. 11), and air drawn through each box at the rate of about 18 litres per hour for ten hours. The air, after passing over the leaves, was deprived of its carbon dioxide by means of caustic soda solution, and the amount of absorbed carbon dioxide determined by neutralization with standard acid, using methyl orange as indicator, after neutralization with phenolphthalein as indicator.¹ By comparison with a "blank"

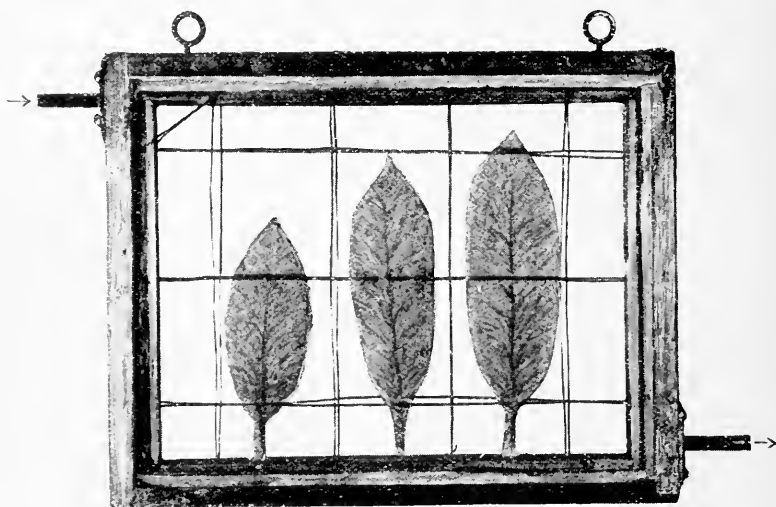


FIG. 11.—Apparatus for testing amount of carbon dioxide assimilated by leaves.

test the amount of carbon dioxide assimilated can be estimated. The insolation boxes were fixed outside a window with a westerly aspect, so that they received no direct radiation until late in the day, and the disturbing effect of solar heat was consequently minimised.

The intensity of daylight was measured as described on p. 32, and the area of the leaves was ascertained by means of a planimeter. In every experiment leaves from the neighbourhood of station 9 were used as the standard of comparison. Experiments 1–3 were of a preliminary nature, to test the

¹ Brown and Escombe, *Phil. Trans.* (1900), **193**. 289; Amos, *Journ. Agric. Science* (1907), **1**. 322.

reliability of the method. The result of Experiment 3 indicates the degree of concordance that was obtained between the rates of assimilation by different sets of leaves from the same district.

The differences in temperature and light intensity on the different days are shown by the varying rates of assimilation of the "standard" leaves, which range from 5.95 mgrms. of carbon dioxide per 10 sq. in. of leaf surface on a cold and rather dull day (Experiment 1) to 17.2 on a warm and sunny day (Experiment 2).

The laurel plants found in the more polluted areas were all very stunted in size, as compared with those growing near station 9, and consequently only medium-sized leaves could be obtained from these districts. A photograph of these leaves, which represent typical specimens from each locality, is reproduced in Fig. 12.

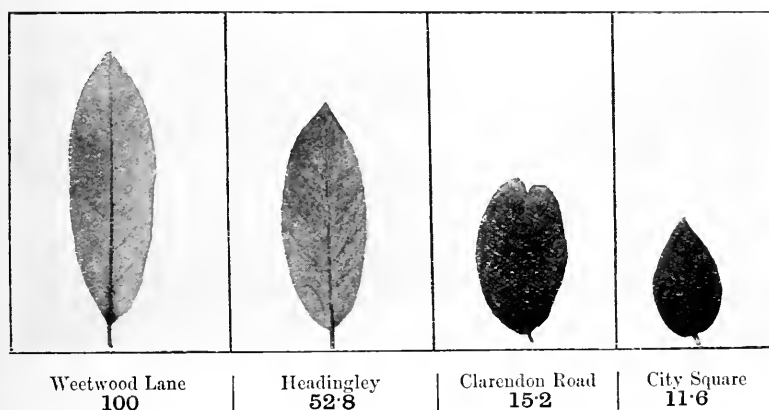


FIG. 12.—Laurel leaves and their respective assimilations.

The greatly reduced assimilatory powers of these leaves, due to the direct and indirect inhibitory effects of atmospheric impurities, are well illustrated in the results of the experiments. Thus, if the assimilatory powers of leaves from station 9 equals 100, those of the leaves from the other stations are represented by the following numbers:—

Station 5	.	.	.	53
" 7	.	.	.	42
" 1-7	.	.	.	15
" 4	.	.	.	11.5

The great reduction in the power of assimilation in passing from the non-industrial area of station 7 to the more contaminated areas of stations 4 and 5 is very striking.

In order to test the effect upon the rate of assimilation of the actual solid deposit found upon the leaves from the two last-named areas, Experiments 6 and 7 were repeated after carefully removing the soot with a dry cloth, the "standard" leaves being similarly treated. The results were as follows:—

Station 9	100
„ 1-7 cleaned	24}
„ 1-7 not cleaned	15}
„ 4 cleaned	19 }
„ 4 not cleaned	11·5 }

The effect is thus a measureable amount, although the power of assimilation of the cleaned leaves does not reach that of leaves grown in the atmosphere of station 9, which is freer from soot. The difference is readily accounted for by the clogging of the stomata, and the consequent lowering of the vitality of the plant.

In connection with the early decay of the leaves of trees and shrubs grown in or near large towns, reference may be made to the analyses of deposits on aucuba leaves carried out by the Air Analysis Committee of the Field-Naturalists Society of Manchester. These analyses, which were made in Dec. 1890 and Jan. 1891, give the quantities of soot, sulphuric acid and hydrochloric acid in the deposit.¹

Deposit on Aucuba Leaves

In milligrams per sq. metre of leaf surface.

Date.	Locality.	Solid Deposit.	Sulphuric Acid.	Hydrochloric Acid.
1890				
Dec. 14	Suburban { Near Alexandra Park	131	7·2	9·1
„ 13		315	10·4	17·3
„ 16		420	26·0	—
„ 14		443	19·0	4·4
„ 14		728	27·5	19·4
„ 14	Urban { Infirmary (hollies) .	568	18·3	14·1
„ 13		833	24·2	21·7
1891				
Jan. 17	Sub-urban { Peel Park	374	18·0	—
„ 22		194	17·5	—

¹ Report of the Air Analysis Committee of the Town Gardening Section, 1891.

It will be seen that the central localities show the largest deposits of soot and acid, the sulphuric acid forming 6 to 9 per cent., and the hydrochloric acid 5 to 7 per cent. of the total deposit.

The deposition of acid along with soot previously recorded by Dr. Russell (see p. 7) is probably one of the chief causes of the early withering which is characteristic of many forms of town vegetation.

Ash trees in the cleaner parts of Leeds often retain their leaves some four or even six weeks longer than those in the more polluted districts. Thus, during the autumn of 1908, near station 10, with a total suspended matter of 26 tons per square mile and acidity nil, ash trees were found in full leaf on November 17th; near station 9, with suspended matter 42 tons per square mile, and acidity equal to about 3 tons of sulphuric acid per square mile, the leaves had all fallen before the end of October, though a few were found still in leaf on the 22nd of that month; at station 8, with suspended matter 100 tons and acidity equal to 2.28 tons per square mile, one ash tree only could be found in leaf on October 5th; whilst at station 5, with suspended matter 189 tons and acidity 3.14 tons per square mile, all the leaves had fallen from ash trees on that date.

On September 18th, 1911, in Hunslet practically all the leaves had fallen from the ash trees which were still alive; at the University a few leaves only were left; at Headingley Hill the tops of the trees only had shed their leaves, while in the Weetwood Lane and Roundhay districts they appeared all to be in full vigour. By October 30th no leaves at all were left on the ash trees near the University; a few were still left at Headingley Hill; in the Weetwood Lane about half had fallen, while at Roundhay many of the trees appeared to have hardly shed a leaf (Figs. 13 and 14).

Looking upon the leaf, then, as the factory of the plant, we find in the more contaminated districts this factory totally closed for one month of its working year, while, for the remainder of the time, as the assimilation experiments on p. 23 show, it is only working at half its normal pressure.

The tree automatically keeps a record of its yearly growth, and the presence of any inhibiting factor will make itself known by the narrowing of the annual rings. This is well seen in the

case of the section of the Scotch fir, illustrated in Fig. 15, for which we are indebted to Mr. D. W. Steuart. The tree in question was grown at Broxburn, near the Roman Camp Shale Works, which were started 17 years before it was cut down. In consequence of the acid fumes and smoke-contaminated atmosphere, the diameter growth as measured by the annual ring was sharply checked when the tree was 12 years old, though



Hunslet.

Suspended matter . 1565 lbs. per acre
Acidity 90 „ „



University.

Suspended matter . 399 lbs. per acre
Acidity 26 „ „



Headingley Hill.

Suspended matter . 273 lbs. per acre
Acidity 185 „ „



Weetwood Lane.

Suspended matter . 147 lbs. per acre
Acidity 11 „ „

FIG. 13.—Ash trees, Sept. 18th, 1911.

under normal circumstances it would be fairly constant up to 30 years old, and then fall steadily off (Fig. 15). This sharply defined check in the growth of the tree, as recorded by itself, is coincident with the opening of the shale works in 1893.

Experiments are now in progress in the Agricultural Department of the Leeds University to find if it is possible to correlate the known atmospheric impurities in the different parts of the town with the yield of various crops.

With this object, soil was taken from the same bulk and placed in tubs which were distributed at six different stations in

and near Leeds. They were sunk in the ground in open situations and sown with radishes on April 11th, 1911. In order to ensure even sowing, wire netting ($1\frac{1}{2}$ inch mesh) was placed over the tubs, and one seed dropped into each mesh (75 seeds in each tub), and three tubs were placed at each station.

They were afterwards thinned out to 30 plants, and the 90 plants from each station lifted on June 30th, weighed, dried and



University.

Soot . . . 399 lbs.
Acid . . . 26 „



Headingley Hill.

Soot . . . 273 lbs.
Acid . . . 19 „



Weetwood Lane.

Soot . . . 147 lbs.
Acid . . . 11 „



Roundhay.

Suspended matter, 90 lbs. per acre. Acidity, nil.



FIG. 14.—Ash trees, Oct. 30th, 1911.

analysed. The conditions, except of course those determined by atmospheric impurity, were identical. The following are the results :—

Analyses of Radishes Grown at different Centres.

Station.	Total weight of crop. grams.	Total weight dry matter. grams.	Average weight of each plant. grams.
Weetwood Lane	496	60.6	5.5
Headingley	449	51.8	5.0
Garforth	395	49.0	4.4
University	297	35.6	3.3
Park Square	242	32.2	2.7
Hunslet	226	23.1	2.5



FIG. 15.—Section through stem of Scotch fir.



Weetwood Lane.
5.5 grams.



Headingley.
5.0 grams.



Garforth.
4.4 grams.



University.
3.3 grams.



Park Square.
2.7 grams.



Hunslet.
2.5 grams.

FIG. 16.—Photographs of radishes grown at different centres, with average weight of plant.

The radishes were followed by a crop of lettuces, which were lifted on September 19th, after receiving as far as possible exactly similar treatment. Here the differences in weight were



Garforth.
175 grams.



Weetwood.
140 grams.



Headingley.
120 grams.



University.
104 grams.



Park Square.
56 grams.



Hunslet.
44 grams.

FIG. 17.—Photographs of lettuces grown at different centres, with total weight of crop.

even greater than the above, only one quarter of the crop being secured in Hunslet that would have been secured had the atmospheric conditions been purer, and the smoke pollution less.

Yield of Lettuces Grown at different Centres.

Station.	Solid Deposit. lbs. per acre.	Acidity. lbs. per acre.	Total weight of Crop. grams.	Total weight of Dry Matter. grams.
Garforth	—	—	175	18·2
Weetwood Lane . .	147	11	140	15·1
Headingley Hill . .	273	19	120	11·4
University	399	26	104	10·2
Park Square	847	45	56	5·3
Hunslet	1565	90	44	4·4

9. Influence of Smoke on the Intensity of Light

The presence of suspended matter in the atmosphere has a marked effect upon the amount of sunshine. As an illustration, we may take the year 1907, when the number of hours of sunshine registered by a Jordan recorder at station 4 in the centre of Leeds was 1167, as compared with 1402 at Adel about 4 miles to the north; in other words, the duration of sunshine in the centre of the city was diminished by 17 per cent. The records for other years tell a similar tale. But the sunshine recorder takes no account of the intensity of light below a certain limit of brightness. The amount of daylight may, however, be determined sufficiently accurately for comparative tests by the amount of iodine liberated from an acid solution of potassium iodide. A mixture of 50 c.c. of a 1 per cent. solution of potassium iodide and 10 c.c. of dilute sulphuric acid was exposed, and at the end of 24 hours the liberated iodine was estimated by titration with standard thiosulphate solution. Two sets of experiments have been made, one in 1895, chiefly during the winter months, at Kirkstall Road (between stations 1 and 4), at station 4 and at station 7, and another set in 1910, which were carried out during the month of June. The two sets of experiments are recorded in the following tables, the numbers giving the amount of the thiosulphate solution required to remove the free iodine.

Light Tests.

SET I.

Being a comparison of the total daylight in different parts of Leeds.

Date—1895.	Station 7. Woodhouse Moor.	Station 4. Philosophical Hall.	Station 1-4. Kirkstall Road.
July 1—7	—	78·30	—
8—14	—	88·30	83·60
15—21	—	61·70	60·60
22—28	—	65·30	58·50
Nov. 10—16	22·94	—	20·61
17—23	15·92	—	12·25
24—30	10·20	—	6·10
Dec. 1—7	10·90	—	10·34
8—14	18·30	—	7·17
15—21	4·50	4·80*	3·53
29—4	2·60	1·99	1·53
Jan. 5—11	4·65	2·32	2·51
12—18	7·88	5·60	5·51
19—25	8·17	5·90	5·47
26—1	13·66	9·02	8·04
Feb. 2—8	6·56	7·20*	7·58*
9—15	8·28	9·05*	10·57*
16—22	3·82	4·40*	3·26

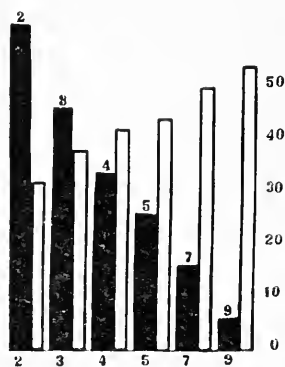
To economise space the results for each week are added together.

* The six numbers marked with an asterisk are exceptions to the general rule. For some unexplained reason, the amount of light registered on these dates is greater near the centre of the town than on the open moor.

SET II.

Date—1910.	Station 2. Huslet.	Station 3. Beeston Hill.	Station 4. Philosophical Hall.	Station 5. Headingley.	Station 7. Observatory.	Station 9. Weetwood Lane.	Station 11. Garforth.
May 29	5·5	5·4	—	6·2	—	6·8	7·2
„ 30	4·6	4·6	—	5·1	—	5·8	6·3
„ 31	3·2	3·6	—	4·4	—	5·2	5·6
June 1	3·5	3·8	—	4·9	—	4·6	5·3
„ 2	4·7	4·8	—	4·9	—	5·6	5·7
„ 3	5·4	5·4	5·4	5·7	5·5	5·9	5·6
„ 4	2·9	2·9	3·2	3·4	3·6	3·8	4·2
„ 5	3·0	3·5	3·8	4·3	5·1	5·4	4·5
„ 6	2·9	3·1	4·6	4·8	5·0	5·6	6·3
„ 7	4·5	4·8	5·6	5·7	5·9	6·1	6·7
„ 8	2·1	3·9	4·5	4·8	5·0	5·2	5·8
„ 9	2·2	4·2	4·2	4·4	4·6	4·5	4·9
„ 10	2·0	2·4	4·2	4·4	4·7	5·0	4·8
„ 11	2·0	3·6	3·6	3·9	4·7	5·2	5·0
„ 12	3·3	5·2	5·9	6·0	6·3	6·4	6·8
„ 13	2·0	4·6	4·9	5·0	5·1	5·2	5·6
„ 14	3·1	4·0	4·9	5·1	5·3	5·2	5·0
„ 15	2·1	3·2	4·1	3·9	4·6	4·8	5·1
„ 16	2·1	3·5	4·1	4·0	4·5	4·9	4·7

It will be seen from the first table that in the centre of the industrial area the smoke cloud occasionally absorbs as much



2. Hunslet. 3. Beeston Hill.
4. Philosophical Hall.
5. Headingley. 7. Observatory.
9. Weetwood Lane.

FIG. 18.—Influence of suspended matter on intensity of light.

as 25 per cent. of the total daylight as compared with the suburban parts of the town, whilst from the second table which includes Garforth, seven miles from the town, it appears that fully 40 per cent. of the light was shut out from the industrial area represented by station 2.

The results exhibit a striking relation between the amount of suspended matter in the air and the intensity of the light.

These relations are indicated by the dark and light columns in the diagram of Fig. 18, the dark column giving the relative proportion of suspended matter carried

down by rain (p. 17), and the light column the relative total daylight. The amount of daylight is thus seen to vary inversely with the amount of soot in the atmosphere.

GASEOUS IMPURITIES

1. Sulphur Acids

COAL contains small quantities of sulphur, the amount of which varies between 1 and 2 per cent. On complete combustion the sulphur is evolved as sulphur dioxide, which in contact with air and moisture passes rapidly into sulphuric acid. This acid is a strongly corrosive substance. It attacks mortar, masonry, fabrics, and metal-work, and is highly injurious to vegetation, as we shall presently see. Coal is practically the sole source of this acid in town air; for in pure country air it is virtually absent. Dr. Rideal¹ has calculated that if all the sulphur from 16 million tons of coal consumed annually in London passed into the air as sulphuric acid, it would represent from one-half to one million tons of acid.

In incomplete combustion, such as occurs more particularly in the domestic grate, a portion of the sulphur is retained in the cinder, and some in the soot. Cohen and Hefford² found, that the distribution of the sulphur in the products of combustion of two kinds of coal, burnt in an ordinary grate in percentages of total sulphur, was as follows:—

Distribution of Sulphur Compounds from Burning Coal.

	A	B
Passing out as sulphur gases	71·78	60·00
Absorbed in the soot and mainly escaping	14·51	11·88
Left behind in the cinder	13·71	28·13

Of that which is retained in the soot, a part is in the form of free acid, as seen from the following analyses:—

¹ *Coal Smoke Abatement Conference*, 1905.

² *Journ. Soc. Chem. Ind.* (1893), **12**, 121.

Source of Soot.	Sulphur.	Acidity.
Leeds University, fire-grate chimney .	2.99	0.37
" " boiler chimney . . .	2.67	1.33
Winston Gardens, dining room . . .	2.45	0.92
" " kitchen	2.20	0.28
North Grange Mount, study	2.32	0.50
" " kitchen	1.46	0.50

Rideal¹ found in samples of soot from London, Manchester, and Glasgow, an amount of acid corresponding to 4.6, 4.3, and 7.9 per cent. of SO_3 respectively. The soot which fell on the glass roofs in the gardens of Kew and Chelsea contained nearly 5 per cent. of SO_3 .

The deposition of acid along with soot upon the leaves of plants is a matter of no small importance, for it is probably one of the chief causes of the early withering of leaves which is so characteristic of trees growing in and near towns.

The amount of sulphur compounds, present as free sulphurous or sulphuric acid, or in combination as sulphate in London air, has been very exhaustively studied by Dr. W. J. Russell.²

Dr. Angus Smith, in his work on "Air and Rain," gives a few analyses of samples of rain, and suggests that much might be learnt of the composition of the air by examining the impurities carried down by rain-water.

Dr. Russell employed this method, and later devised a process for washing large quantities of air. He found the principal impurities in the rain of towns to be sulphates and chlorides, and expressed these as sulphuric acid and hydrochloric acid per litre of rain-water. The amount of free acid was not estimated, as the majority of the samples, unlike Leeds rain, gave no acid reaction. Three stations were selected, one in the city at St. Bartholomew's, and two suburban stations at Hamilton Terrace and Shacklewell. The amount obtained in parts per million were as follows:—

	H_2SO_4 in parts per million.	HCl in parts per million.
St. Bartholomew's . . .	38.8	17.9
Hamilton Terrace . . .	19.6	8.8
Shacklewell	20.7	7.8

¹ For complete analyses, see Appendix B., p. 77.

² *The Monthly Weather Report of the Meteorological Office*, Parts I., II., and III., April, 1884, and August, 1885.

Thus, the city rain contained twice as much impurity as that collected at the suburban stations. Dr. Russell also found that at all three stations there was a notable increase in the proportion of sulphate during the summer months, which he put down partly to evaporation of the samples, and partly to volatile sulphur compounds being emitted from decomposing animal and vegetable matter.

Some experiments made by condensing and collecting the moisture in the air at St. Bartholomew's showed the same ratio of sulphate to chloride as well as the same amount per million parts as that in rain-water of the same locality.

An interesting illustration is also given of the purifying effect of rain on the atmosphere in the analysis of samples at the beginning (I) and end (II) of a downpour.

	St. Bartholomew's.		Hamilton Terrace.		Shacklewell Green.	
	I.	II.	I.	II.	I.	II.
Sulphates . . .	39·7	33·1	33·1	11·0	39·7	13·2
Chlorides . . .	8·7	3·6	3·6	1·4	5·8	2·8

The best series of analyses of country rain are those of Messrs. Lawes, Gilbert, and Warrington of rain collected during thirteen months at Rothamsted, the means of which are as follows:—

	Parts per million.
Sulphates	4·0
Chlorides	3·3

The proximity of the sea in increasing the amount of chloride is seen in the analysis of rain collected on Dartmoor during a south-westerly storm.

	Parts per million.
Sulphates	0·5
Chlorides	8·7

We will now compare our own results of the analyses of sulphur and chlorine compounds contained in the monthly samples of rain collected at the ten Leeds stations and Garforth, giving the maximum and minimum for the year.

*Variation in quantity of Sulphur and Chlorine Compounds in
Leeds Rain.*

(Parts per Million.)

Station.	Sulphur			Free acid expressed as H_2SO_4 .		Chlorine.	
	As sulphate, max. min.	In other forms, max. min.	Total. max. min.	max.	min.	max.	min.
	SO_3	SO_3	SO_3				
1	29.3 11.2	10.4 0.0	39.7 11.2	9.8	0	29.2	10.8
2	34.1 15.1	8.9 1.4	42.1 17.2	14.7	0	33.2	9.1
3	87.2 17.4	25.3 3.7	85.1 21.1	11.7	0	15.8	9.0
4	65.5 16.3	17.7 2.1	83.2 26.4	18.8	0	43.2	4.7
5	33.2 17.2	11.1 3.7	42.2 24.3	3.3	1.1	24.9	5.9
6	31.8 13.3	10.9 1.1	36.7 17.8	12.7	0	14.1	8.3
7	25.9 9.4	32.6 0.9	58.5 10.3	10.8	0	33.2	2.5
8	25.7 8.9	9.0 2.6	33.5 11.4	4.6	0	8.3	4.3
9	30.8 9.3	8.3 0.0	38.0 10.4	7.5	0	19.8	1.3
10	18.3 5.0	4.9 0.0	23.2 6.2	0	0	9.3	2.3
11	16.5 7.3	9.7 1.0	26.2 8.3				

In the specimens of snow gathered on four consecutive days, and referred to on p. 14, the following quantity of sulphates was found:—

Sulphates in Snow calculated as SO_3 in parts per Million.

First day . . .	6.3	} 3.0
Second . . .	9.3	
Third . . .	13.1	} 3.8
Fourth . . .	19.7	
		} 6.6

These results cannot, of course, be compared with sulphates carried down by rain, but are interesting as showing a steady accumulation of this impurity even in clear weather on the surface of the ground.

Taking the amount of sulphur compounds in the whole of the rain during the year, and estimating it as tons to the square mile, we arrive at the following results:—

Sulphur in Leeds Rain.

Tons per square mile per annum.

Station No.	Free acid expressed as sulphuric acid.	Sulphur compounds expressed as SO_3 .		
		As sulphate.	In other forms.	Totals.
1	10.0	35.2	12.3	47.5
2	26.7	52.9	8.6	61.5
3	8.5	77.0	19.1	96.1
4	12.9	42.5	13.7	56.2
5	3.1	32.3	11.4	43.7
6	8.3	31.4	13.1	44.5
7	7.5	24.3	14.0	38.3
8	2.3	22.0	20.0	42.0
9	3.1	23.4	4.5	27.9
10	0.0	15.1	5.7	20.8
11	8.0	18.6	7.4	26.0

The above results are reproduced in the following diagrammatic form, in which the vertical columns in Fig. 19 give the

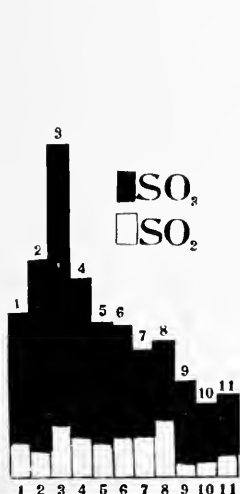


FIG. 19.—Relative amount of total sulphur.

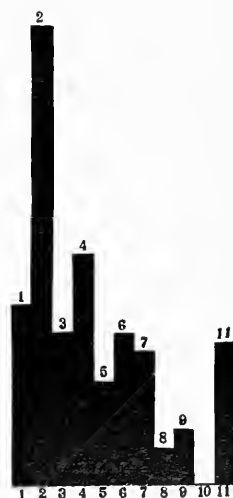


FIG. 20.—Relative amount of acidity.

amount of total sulphur, the unshaded part representing the proportion present as sulphurous acid, and the shaded part

the amount of sulphuric acid either free or combined. The second diagram (Fig. 20) gives the amount of free acid.

It is thus shown that the total sulphur in the form of sulphurous or sulphuric acid is everywhere high, but particularly so in and near the chief manufacturing areas. Fortunately a large proportion of these acids is neutralized either by the alkaline fumes thrown out by the blast furnaces, or by ammonia emitted at the same time from the burning coal (p. 57). Nevertheless free acid is present in large proportion, and represents in Hunslet an annual deposit of nearly 27 tons to the square mile.

Although it is the sulphurous acid which imparts to town fog its acid and irritating effects (see p. 63), it is the sulphuric acid which is mainly responsible for the serious damage produced on masonry and vegetation.

Before concluding this section on the subject of sulphur compounds in air, reference should be made to Dr. Russell's experiments on washing air (*loc. cit.*). The air was pumped into a wide vertical glass cylinder 2 feet 9 inches long and $2\frac{3}{4}$ inches in diameter, which was divided vertically and horizontally into compartments by means of wire gauze. The lower end of the washing cylinder was open and placed a little above the bottom of a glass vessel holding 400 c.c. of water. On working the pump the air forces the water into the cylinder and breaks it into a spray. A second washing vessel is attached to collect anything which might have escaped from the first. The apparatus is shown in Fig. 21.

The mean of 27 experiments, which are divided into three groups of fine, dull, and foggy weather, are expressed in mgrms. per 100 cubic feet as follows:—

	Sulphates as Sulphuric acid.	Chlorides as Hydrochloric acid.
Fine weather	1·28	0·10
Dull " 	3·19	0·36
Foggy " 	4·6	0·28

2. Effects of Sulphuric Acid on Masonry

Among the earlier records of the action of the acid in the atmosphere on buildings are those of Dr. Angus Smith, who found in mortar 28·33 per cent. of sulphuric acid, equal to 48·16

of calcium sulphate, produced by the action of the acid on the lime. The white efflorescence which sometimes appears on

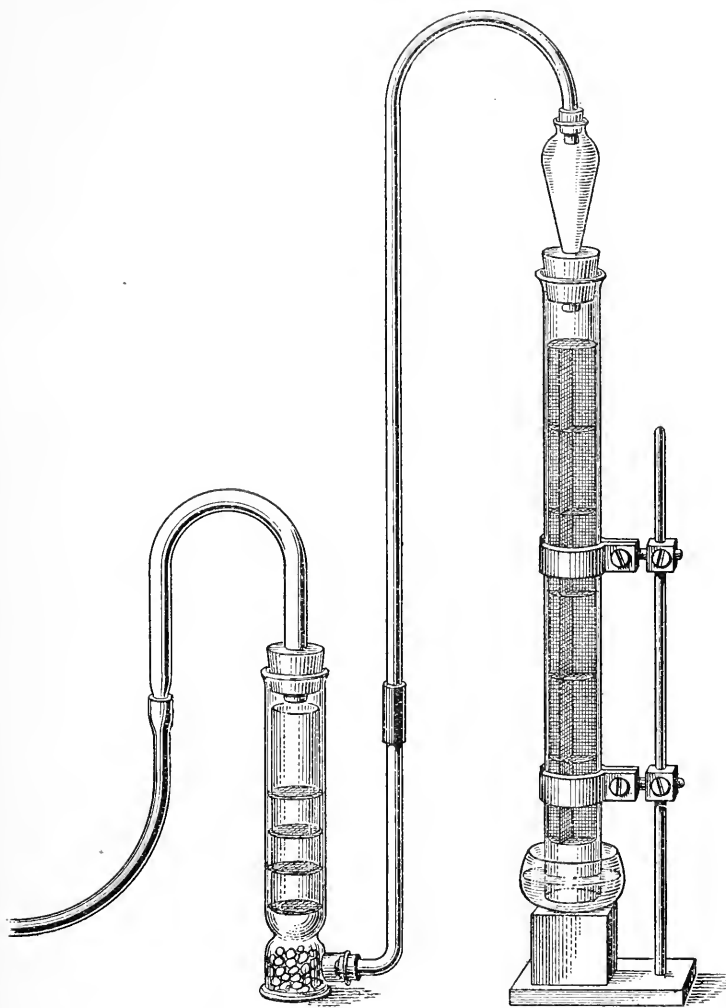


FIG. 21.—Dr. Russell's apparatus for washing air.

brickwork is mainly composed of calcium or magnesium sulphate, and, according to the same authority, one of the chief causes of damage done by soot and smoke is the decay of

mortar. It swells, becomes porous, and falls to pieces at the slightest touch.

We are indebted to Prof. H. Jackson of King's College, London, for some of the results of his very careful and comprehensive inquiry into the effects of atmospheric sulphuric acid on the corrosion of masonry. On the stones from one historic building he reports: "All consisted mainly of calcium carbonate, being almost entirely soluble in hydrochloric acid. They showed evidence of weathering and disintegration. The surfaces of most were soft and friable, and one was so very loose and rotten that it could be removed to a depth of $\frac{1}{4}$ inch by mere rubbing. Two only had to be chipped in order to obtain portions for analysis. Chemical examination of the friable portions and of the unaffected inside of each of the stones showed that the disintegration could be ascribed to the action of sulphuric acid, which had converted part of the calcium carbonate into calcium sulphate. This was associated with an alteration in the structure of the surfaces, resulting in a loosening of the particles which had previously been cemented by the silicates, which exist in small amounts as constituents of all the stones. The amount of calcium sulphate taken $\frac{1}{8}$ inch from the surface varied from 3.2 to 33.5 per cent. In one case calcium sulphate was found at a depth of nearly $\frac{1}{2}$ inch, but there was no change below that. The friability was not always proportional to the amount of calcium sulphate. Disintegration depends on the original character of the stone. Also the amount of calcium sulphate, which is soluble in water, may not represent the full extent of the conversion owing to its removal by rain." In another case he reports—

"The stone consists of calcium carbonate in granules, bound together by small quantities of calcium and aluminium silicate. A quantitative examination of scrapings taken from the inside of large pieces of stone showed that the disintegration of the stone could certainly be ascribed to the action of sulphuric acid. This acid, acting readily on the calcium carbonate, converts it into calcium sulphate and carbon dioxide. Analyses of the calcium sulphate in the stone gave 4.75 to 15.81 per cent. on the outside, and 0.23 to 2.8 on the inside. It will be seen that fairly extensive chemical action has taken place on the outside of the stonework, but that this action has not penetrated

very deeply. Limestones vary in the readiness with which they are disintegrated by the action of sulphuric acid, accompanied by the mechanical effects of wind and rain, and the present stone is somewhat easily affected by sulphuric acid. The decay has resulted from the disintegration of the surface of the stonework, accompanying the conversion of calcium carbonate into calcium sulphate, by the action of sulphuric acid present in the atmosphere. This conversion has been associated with a change in the structure of the stone, so that its granules and crystals, previously held together by the cementing influence of silicates, has been attacked and partially dissolved in such a way as to loosen the hold of the cementing material upon them, and render them easily displaced by the effects of wind, rain, frost, alterations of temperature, and the mechanical disturbance arising from the crystallization of calcium sulphate."

In his report on a Kentish ragstone from a church, Prof. Jackson says:—

"Limestones used for building purposes vary considerably in the amount of acid which can be absorbed by them before they exhibit marked deterioration. Direct experiments on portions of the ragstone show that they are affected prejudicially by relatively very small quantities of sulphuric acid. Analyses of average samples of the friable portions of the outside surfaces of the specimens gave the following percentages of calcium sulphates from 0·52 to 3·85.

"These quantities of calcium sulphate are but small compared with those frequently found in stones which have been exposed for many years to the air of towns, and which show less marked deterioration than that exhibited by the ragstone.

"The evidence of analyses from stones from various points of the building is that the decay of the stone has been primarily caused by the action of sulphuric acid present in the air, but it must be remembered that a stone weakened in its resisting power by such an action becomes much more readily affected by water and carbonic acid, as well as by the mechanical action of frost, winds, etc."

In the course of a report on sandstone from another church, he says:—

"None of the differences in composition (between the

decayed and undecayed portions) can be considered as indicating extensive chemical changes, but it must be remembered that in a sandstone consisting mainly of grains of quartz bound together by small amounts of cementing materials, a relatively slight alteration in composition may mean considerable modification in the cohesive strength of the stone. The changes indicated by analysis are such as would result in a stone of the nature of the specimens from the ordinary process of weathering, assisted by the chemical action of sulphuric acid in the atmosphere. That this acid has played some part in the disintegration appears probable when account is taken of the increase in the amount of it on the surface of the specimens, compared with that present in the body of the stone."

Two further abstracts from Prof. Jackson's report on the stonework of another public building must suffice:—

"The results of the examination and analysis point to the disintegration of the stone having been effected mainly through the agency of the acid vapours contained in the air. Of these the most detrimental have been the sulphurous and sulphuric acid, which arise mainly from the combustion of coal. These, including carbonic acid, water, and alternations of temperature, may be described as the materials and conditions primarily necessary for the decomposition of siliceous stones (sandstones) and limestones. There is practically no evidence of any effects which can be ascribed to hydrochloric acid. In the case of siliceous stones, which consist of silica in the form of grains of quartz cemented together by aluminium silicate and calcium carbonate, the latter has been freely attacked, and its place largely taken by calcium sulphate. This, besides being soluble to an appreciable extent in water, does not act as an agglutinant for the quartz grains, which, consequently, have been rapidly displaced from their former positions.

"Disintegration having once started, would be progressive, not only on account of the continued existence of the primary causes and conditions, but because of the consequent increased porosity of the surface of the stone rendering this a readier absorbent, both of injurious gases and of aqueous solutions, capable of chemically acting upon the materials with which they are thus brought into intimate contact."

The analyses show that in the case of limestones in many

instances more than half the carbonate has been transformed into sulphate on the surface, and in the case of siliceous stones an even larger percentage of the binding carbonate has been transformed.

"It must be borne in mind, in comparing numbers for the percentages of calcium sulphate, that limestones are much more chemically active towards sulphurous and sulphuric acid than siliceous stones, and that, consequently, given the two varieties bathed in the same atmosphere, the limestones would show the higher percentage of calcium sulphate. It does not necessarily follow that they would show the greater disintegration, for with the removal of their cementing and agglutinating portions, the siliceous stones would be readily affected mechanically, as for example, by dust-laden winds and the freezing of water."

3. Effects of Sulphuric Acid on Metal Work

We are indebted to Mr. W. B. Worthington, chief engineer of the Midland Railway, and Mr. A. Rattray, chief engineer of the Lancashire and Yorkshire Railway, for the details of experiments made to ascertain the loss of weight of rails arising from wear and tear, and from corrosion. A number of rails were placed in suitable positions by the side of the line, and weighed at intervals, and the loss of weight recorded. The rails were of the ordinary railway section, weighing about 86 lbs. per yard. The annual loss of weight from corrosion was as follows:—

	Loss of weight in pounds per annum per yard.	Number of years over which obser- vations extended.
(1) In the centre of the town	1.04	17
(2) In a dry place in a smoky tunnel . . .	1.48	13
(3) In a wet place in the same tunnel . .	1.71	8
(4) On the sea coast amongst sand hills .	0.18	17

The effect of smoke is very evident both in the town and in the tunnel. It would appear that the amount of corrosion due to this cause from town air is more than six times that from the purer atmosphere of the sea coast. This action on rails must, of course, be the same for all iron work exposed to the atmosphere, and gives an indication of the widespread amount of corrosion which must be taking place.

4. Effects of Sulphuric Acid on Vegetation¹

In order to examine the effect of sulphuric acid upon vegetation, Timothy grass (a perennial grass) was sown on May 12, 1908, in boxes 1 foot square, filled with soil from a well-mixed heap, and treated exactly alike throughout the experiments with the exception of the watering. They were watered at rates corresponding to the average Garforth rainfall of 25 inches, with waters containing respectively 1, 2, 4, 8, 16, and 32 parts of sulphuric acid per 100,000. Other boxes were watered with Garforth rain-water, with the same water neutralized, and with

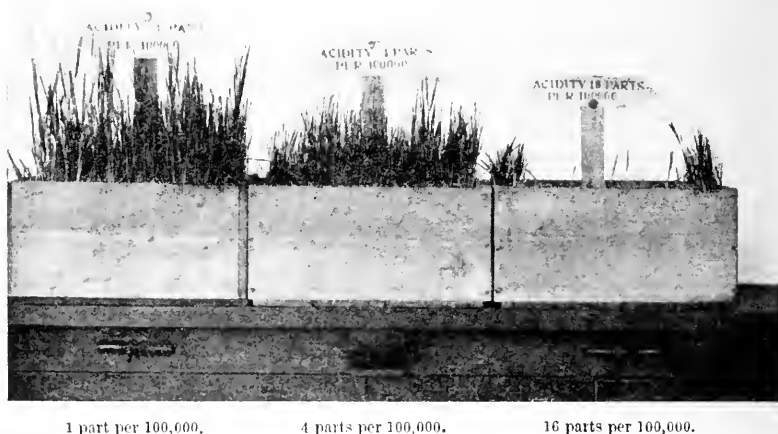


FIG. 22.—Effect of various proportions of sulphuric acid in water.

Leeds rain-water. It may be added that the acidity of the Leeds rain ranges from $\frac{1}{2}$ to occasionally 10 parts per 100,000.

In the case of the Leeds rain-water and of those waters containing the higher degrees of acidity, germination was distinctly checked, and the delicate green of the young grasses quickly changed to a yellow or brown (Figs. 22, 23, and 24).

The grasses treated with water whose acidity was 32 parts per 100,000 were killed off in little more than three months, and not a trace of vegetation of any kind was visible in the

¹ Crowther and Ruston, *Journ. Agric. Science* (1911), 4. 25.

following spring. The water of acidity 16 parts per 100,000, proved fatal in less than a year. The weights and composition of the material grown during the three seasons 1908–1910 are



2 parts per 100,000.

8 parts per 100,000.

32 parts per 100,000.

FIG. 23.—Effect of various proportions of sulphuric acid in water.



Garforth rain neutralized.

Garforth rain.

Leeds rain.

FIG. 24.—Effect of (1) Garforth rain-water neutralized; (2) Garforth rain-water; (3) Leeds rain-water.

recorded in table (p. 48). In addition to the dry matter, the amounts of nitrogen and crude fibre (that is, the indigestible matter) have also been estimated.

It will be observed that in every case the yield steadily decreased with the increased acidity of the water used, and that the effects in this respect were cumulative.

In the first season only the "32 parts" shows any decided fall in the yield. In the following season this specimen was killed, whilst the "16 parts" was *in extremis*, and in 1910 not a trace of vegetation was left; whilst the "4 parts" and "8 parts" show a minimal yield. Even the grass in the "2 parts" box is suffering severely, and, most interesting of all, the Leeds rain is now definitely telling its tale.

The Action of Sulphuric Acid on the Yield of Timothy Grass.

Description of water used.	Total dry matter.			Nitrogen in dry matter.			Crude fibre in dry matter.		
Year...	1908	1909	1910	1908	1909	1910	1908	1909	1910
	gms.	gms.	gms.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Garforth rain, neutralized	28·0	24·9	14·7	2·47	2·22	1·58	24·3	21·9	23·7
„ „ ordinary	24·8	18·5	11·0	2·01	1·75	1·54	25·9	25·3	26·0
Leeds rain	23·8	17·5	6·6	1·96	1·42	1·23	26·4	26·3	27·2
1 part H ₂ SO ₄ per 100,000	30·5	18·2	12·0	1·89	1·61	1·40	25·5	27·3	26·2
2 parts „ „	28·7	17·8	8·0	1·84	1·06	1·09	26·3	28·8	28·7
4 „ „ „	28·8	10·0	3·9	1·74	0·95	0·86	27·4	28·9	28·9
8 „ „ „	24·8	8·2	3·7	1·77	0·89	0·82	28·2	33·4	30·3
16 „ „ „	23·8	1·8	nil	1·62	0·87	—	30·8	36·2	—
32 „ „ „	14·1	nil	nil	0·93	—	—	31·6	—	—

The three photographs reproduced in Figs. 25, 26, and 27 show the appearance of the grass after the first season's growth, the boxes being arranged in order of increasing "parts" of sulphuric acid.

The results of the analyses also show that the increase in acidity, besides reducing the total yield of dry matter, lowered the nitrogen content and increased that of crude fibre. The grass grown with the nine acid waters must obviously be greatly inferior in nutritive value to that grown with neutral or less acid waters. The effect is quite evident in the case even of the grass watered with water containing only one part of acid per 100,000, a proportion which is about the average in Garforth rain, and hence it becomes a matter of importance to ascertain to what extent this deterioration can be traced to the soil of

meadows in smoke-infected areas. The soil in the boxes was therefore submitted to chemical and bacteriological examination by well-known methods.¹

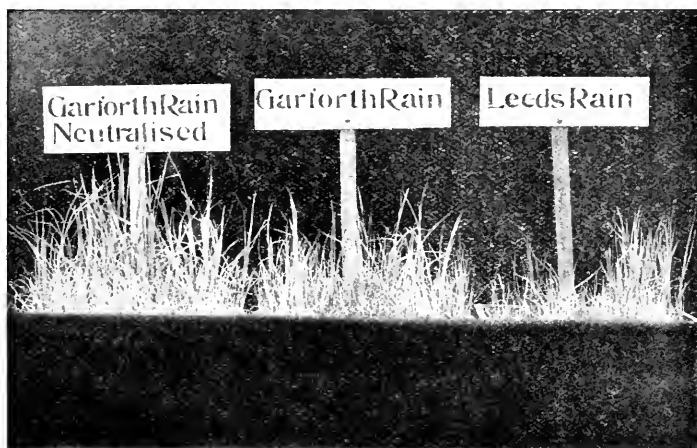


FIG. 25.—Effect of various proportions of sulphuric acid.

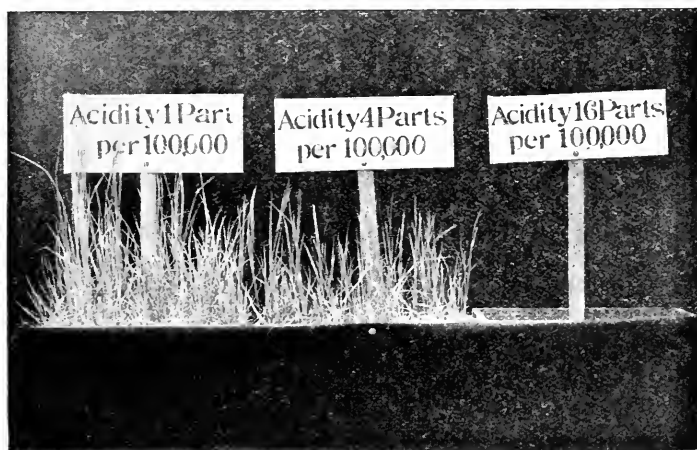


FIG. 26.—Effect of various proportions of sulphuric acid.

¹ The methods used were those of Kjeldahl-Gunning for nitrogen, Russell for ammonia, Dyer for phosphoric acid and potash, Amos for total carbonate, Russell and Darbshire for absorptive power for oxygen, and nitrates were determined by extraction and reduction to ammonia.

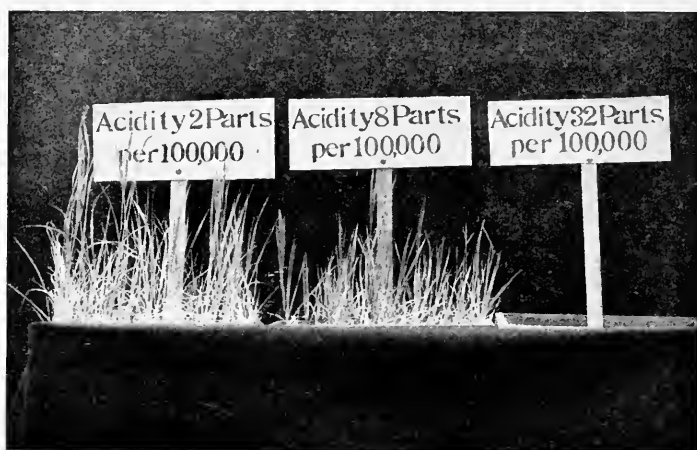


FIG. 27.—Effect of various proportions of sulphuric acid.

Chemical Analysis of Soils.

	Nitrogen.			"Available" P ₂ O ₅ (Dyer).	"Available" K ₂ O (Dyer).	Total carbonate expressed as CaCO ₃ .	Oxygen absorp- tion (Russell and Darbishire).
	Total.	As Ammonia.	As Nitrate.				
	per cent.	per million	per million	per cent.	per cent.	per cent.	mm.
Garforth rain, neutralized .	0.179	3.5	5.8	0.014	0.012	0.23	12
" " ordinary .	0.159	1.4	4.7	0.019	0.019	0.18	9
Lecds rain " .	0.162	2.5	3.7	0.026	0.031	0.14	5
1 part H ₂ SO ₄ per 100,000 .	0.154	2.1	4.1	0.023	0.015	0.16	8
2 parts " " .	0.158	4.9	3.3	0.026	0.021	0.12	6
4 " " " .	0.128	6.8	1.3	0.026	0.026	0.10	4
8 " " " .	0.126	7.9	0.5	0.041	0.029	0.05	1
16 " " " .	0.144	8.1	0.0	0.043	0.042	0.04	3
32 " " " .	0.133	9.4	0.0	0.046	0.043	0.03	0

With the exception of the total nitrogen, a distinct correlation is traceable in all cases between the amount of acid applied to the soil and the different quantities estimated. Thus, increasing acidity has clearly led on the one hand to diminished content of nitrates and of carbonates, and to diminished absorptive power for oxygen, but on the other hand to increased content of the easily soluble mineral ingredients and also of

ammonia. The absorptive power for oxygen thus measured is in effect a measure of the activity of the micro-organisms in the soil, and this diminished absorptive power is a clear index of the general diminished fertility of the soil.¹ The increase in the ammonia-content of the soil with increased applications of acid finds a ready explanation in the results of the bacteriological investigations.

Bacteriological Investigation of Soils.

	Total number of bacteria per gm. of dry soil.	Ammonia produced from peptone.	Ammonia converted into nitrates.	Nitrogen fixed per gm. of mannite.
	thousands.	mgs.	mgs.	mgs.
Garforth rain, neutralized	5228	13.9	1.02	4.6
" " ordinary	1690	12.7	0.84	3.7
Leeds rain	1170	11.7	0.73	3.0
1 part H ₂ SO ₄ per 100,000	1260	12.1	0.80	3.3
2 parts	1100	11.2	0.85	3.0
4 " " "	690	10.5	0.52	2.8
8 " " "	130	10.3	0.36	2.4
16 " " "	40	10.3	0.23	1.9
32 " " "	15	8.1	0.13	1.8

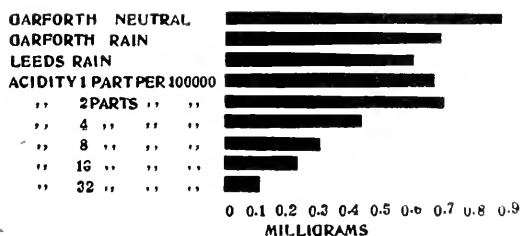


FIG. 28.—Influence of acidity. Nitrogen nitrated.

The influence of the treatment with acid upon the extent and character of the bacterial flora of the soil will be seen to have been very striking, the total number of bacteria diminishing rapidly with increasing acidity, this being reflected also in diminished activity as regards ammonia-production, nitrogen-fixation, and, above all, nitrification.

Ammonia-producing Bacteria.—The activity of these bacteria

¹ Russell and Darbishire, *Journ. of Agric. Science* (1905), 1, 260.

was measured by their effect upon peptone. The procedure in each case was to incubate $1\frac{1}{2}$ grams of the soil with 100 c.c. of a nutrient solution containing 1 per cent. of peptone, but no other source of nitrogen. The incubation at 30° C. was prolonged for three days and the ammonia produced then estimated by distillation with magnesia. In each case a strong growth was obtained at the surface of the peptone solution, but the rate of development and appearance of the film varied so markedly in the different flasks as almost to permit the soils to be graded on this basis alone.

It will be noted that whereas ammonia-production was appreciably more active in the "Garforth Neutral" soil than in those which had received acid waters, the diminution of activity with increasing acidity was very gradual and slight, being only

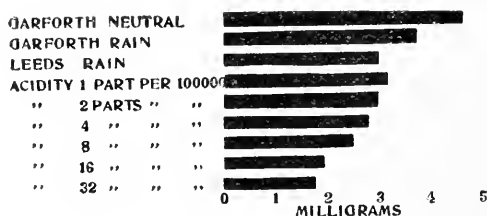


FIG. 29.—Influence of acidity. Nitrogen fixed.

about 25 per cent. less, even in the "16 parts" soil. There was, however, a marked falling off in the case of the "32 parts" soil.

Nitrification.—The most marked effect of the acidity is seen in the reduced activity of the nitrifying or nitrate-producing organisms.

This was investigated in each case by incubating 5 grams of the soil with 100 c.c. of a sterile nutrient medium containing 0.05 gram of ammonium sulphate, 0.5 gram of calcium carbonate being also added. After 21 days' incubation at 30° C. the nitrates formed were estimated colorimetrically by the pierate method. The films obtained were in no case very well developed, which was not surprising in view of the initial poverty of the soil in calcium carbonate. The amounts of nitrate produced were thus in all cases very low, but still the influence of acidity is brought out very sharply. There is again the

general concordance between the results obtained with the two ordinary rain-waters and the "1 part" and "2 parts" soils.

[It will be noted that the activity of the nitrifying organisms was inhibited to a relatively far greater extent than that of the ammonia-producing organisms.] Thus, for instance, in the "4 parts" soil the nitrate-production was only one-half, whereas the ammonia-production was fully 75 per cent. of that in the "Garforth Neutral" soil. This furnishes a ready explanation of the fact, previously recorded, that the ammonia-content of the soils was greater when increased amounts of acid had been applied to them (p. 51).

The conversion of the complex albuminoids originally present in the soil into the soluble nitrates upon which the plant principally feeds, proceeds in at least two stages. The organisms which are responsible for the first change from albuminoids into ammonium compounds are apparently susceptible, though not vitally so, to acid influences. On the other hand, the organisms which are responsible for the final change of the ammonium compounds into nitrates are practically unable to work in the presence of free acids.] Hence, though the activity of the ammonia-producing organisms is distinctly checked, ammonia is still produced. In the case of the higher degrees of acidity the nitrifying organisms are almost non-existent. Thus, the increased application of acid gives an increased ammonia content to the soil, not because more ammonia is produced, but because the smaller amount of ammonia thus produced is incapable of being converted into nitrates, and hence accumulates.

Nitrogen-fixing Organisms.—The activity of these organisms was measured by incubating 1 gram of soil with 0.5 gram of calcium carbonate and 100 c.c. of a sterile nutrient solution containing 2 grams mannite, 0.02 gram each of potassium dihydrogen phosphate, crystallized magnesium sulphate, and sodium chloride, and 0.1 gram of calcium sulphate. After incubation for 13 days at 30° C. the nitrogen-content of the mixture was determined by the Kjeldahl-Gunning method. The amount of nitrogen fixed was then arrived at by deducting the nitrogen originally present in the one gram of soil taken.

The characteristic growth of the nitrogen-fixing organisms has been fully described by Ashby, and the sequence of gas-

production, growth of film, and gradual darkening in colour referred to by him were exactly reproduced in these cultures.

The differences in the rate of development with the different soils were, however, so marked that it was quite possible from the appearance of the cultures to place the soils substantially in the order which was subsequently found to be that of their nitrogen-fixing activities.

Here again, as in the case of nitrification, the application of acid waters to the soil is seen to have exercised a marked inhibitory effect upon the activity of the nitrogen-fixing organisms, the reduction in the case of the soil on which the more impure rain-water (Leeds) was used amounting to practically one-third of the nitrogen-fixing activity of the "Garforth Neutral" soil.

It is also interesting to note that here again, as in the case of the other forms of bacterial activity investigated, the Leeds rain-water exercises an inhibitory effect somewhat greater than that of water containing one part of H_2SO_4 per 100,000, but not greater than that of water containing two parts of H_2SO_4 per 100,000. This accords precisely with the indications of the yields of dry matter and with the results of the analyses of Leeds rain samples recorded in p. 38.

To sum up, the presence of free acid in the atmosphere exercises a detrimental influence upon plant growth by direct action upon the leaves, and by indirectly reducing the activity, not only of the necessary ammoniacal fermentation of the soil humus, but even more by lowering the activity of the nitrifying and nitrogen-fixing organisms in the soil. Moreover, the continued application to the soil of acid rain produces a grass distinctly poorer in protein and richer in fibre, and consequently less nutritious.

The presence of smoke contamination is usually made manifest by an increased sulphur content in the leaves of trees and plants.

The following analyses by Mr. D. R. Stewart, of Broxburn, of the leaves of conifers illustrate this point very clearly.

Spruce Leaves.

Source of leaves.	Percentage of SO ₃ in original leaves.
1. Roman Camp, very near shale retorts	0.28 per cent. of total weight
2. Ecclesmachan, country village in neighbourhood of shale works	0.12 „ „ „
3. Near Dumfries, in open country	0.07 „ „ „

Scotch Fir.

1. Roman Camp	0.19 per cent.
2. Near Dumfries	0.06 „

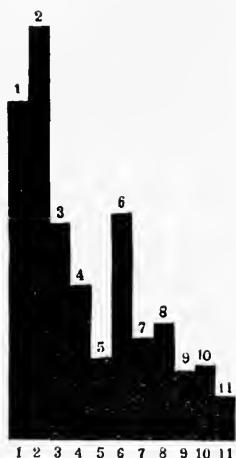
In the case of leaves of the same age and from the same plant, collected from localities where the sulphur content of the air has been determined, a striking correlation is observed between the SO₃ content in the dry matter of the leaves and the annual deposit of SO₃ from the air as previously determined.

Station.	Yearly deposit of SO ₃ in lbs. per acre.	Percentage of SO ₃ in dry matter of leaves.		
		Ash tree.		Lettuces.
		Total.	After cleaning.	
		Per cent.	Per cent.	Per cent.
1. Hunslet	215	4.52	3.15	3.22
2. Park Square	197	4.16	—	2.61
3. University	134	—	—	1.99
4. Headingley Hill	116	3.73	3.03	2.02
5. Weetwood Lane	98	3.52	2.27	1.53
6. Garforth	91	—	—	1.20

It would appear, therefore, that in the more smoke-infested areas, not only is there an increased deposit of sulphur compounds with the soot upon the surface of the leaves, but that there is also an increased intake of SO₂, probably through the stomatal openings.

5. Other Gaseous Products of Combustion and their Effects

Chlorides are found in large quantities in the atmosphere, especially in industrial areas, where, expressed as common salt, they sometimes reach as much as 100 to 130 tons per square mile of surface. The amount carried down by rain at the different stations previously referred to is shown in the following



1. Leeds Forge. 2. Hunslet.
3. Beeston Hill. 4. Philosophical Hall. 5. Headingley.
6. Armley. 7. Observatory. 8. Kirkstall.
9. Weetwood Lane. 10. Roundhay. 11. Garforth.

FIG. 30.—Relative amount of chlorine.

diagram (Fig. 30) by means of the shaded columns. The actual quantities, together with the content of ammonia estimated in the same samples of rain, are given in the table at the end of this section.

That the greater part of these chlorides are purely local is proved by the following facts: They diminish rapidly in amount on passing northwards from the centre of the town. Thus at the Philosophical Hall they represent $21\frac{1}{2}$ tons per square mile; one mile out they fall to $14\frac{1}{2}$ tons; and two and a half miles out they fall again to 10 tons per square mile. Furthermore, the average chlorine content, as given by Angus Smith, of rain collected in inland country places in England is 3.88 parts per million, a figure practically identical with the average at Garforth, $7\frac{1}{2}$ miles distant. In an industrial centre like Hunslet the average

rises to 35.43 parts per million, or nearly 10 times as much.

An excess of chlorides taken alone is no proof of a bad atmosphere, for they naturally increase in quantity the nearer the vicinity to the sea; but an excess in an inland district above the amount in the surrounding area is a clear proof of contamination from an industrial source. Of the 54 tons of chlorine per square mile deposited each year at Hunslet, 6 tons may be ascribed to the sea-spray, and the remainder to the impurities derived from blast-furnaces, glass-works, and potteries, as well as from the coal itself.

The nitrogenous impurities would all be distinctly beneficial to vegetation, either acting directly as stimulants and fertilizers or neutralizing the acidity due to the presence of sulphur or chlorine compounds. They are derived mainly from the nitrogen originally present in the coal, and also, in a smaller degree, from decomposing organic matter and from the direct oxidation of free nitrogen of the air. In this case there does not appear to be the great variation in the amount in different parts of the town that is shown by other impurities, the highest representing 7 tons and the lowest $2\frac{1}{2}$ tons to the square mile. It is, however, interesting to note that nitrogen, in the form of nitrates, is found only in the cleanest localities, and that the organic nitrogen is found in the largest quantities in the industrial areas.

The diagram of Fig. 31 represents, by vertical columns, the variation in the amount of nitrogen in the form of ammonia (black), organic nitrogen (shaded), and nitrates (blank), found in rain-water of the various stations.

The actual analytical results are shown in the following table :—

Chlorine and Nitrogen in Leeds Rain.

Tons per square mile.

Station No.	Chlorine.	Nitrogen			
		as ammonia.	as nitrate.	as albuminoid.	Total.
1	47.0	3.71	0.00	1.34	5.05
2	56.5	4.43	0.00	0.83	5.26
3	29.0	4.11	0.14	1.00	5.25
4	21.4	4.11	0.08	0.63	4.82
5	11.7	3.17	0.31	0.23	3.71
6	31.0	2.83	0.28	0.91	4.02
7	14.6	2.65	0.23	0.46	3.34
8	16.3	2.20	0.05	0.65	2.90
9	9.7	2.37	0.31	0.60	3.28
10	11.0	1.65	0.20	0.37	2.22
11	6.3	1.43	0.91	0.31	2.65



1. Leeds Forge. 2. Hunslet. 3. Beeston Hill. 4. Philosophical Hall. 5. Headingley. 6. Armley. 7. Observatory. 8. Kirkstall. 9. Weetwood Lane. 10. Roundhay. 11. Garforth.

Fig. 31.—Relative amount of nitrogen.

6. Arsenic in Coal, Soot, and Rain

Dr. Russell, in his exhaustive study of atmospheric impurities, already referred to (p. 36), had looked for and discovered arsenic in London rain-water to the extent of 0.0003 part per million.

It is well known that most kinds of coal contain small quantities of arsenic, probably due to the presence of arsenical pyrites. A large number of estimations of arsenic in coal were made in connection with the Royal Commission which inquired into cases of poisoning with beer containing arsenic.¹ In these analyses the quantity varied from a trace to 0.13 per cent. calculated as As_2O_3 . In addition to this, Mr. T. Fairley, city analyst for Leeds, investigated household dust from different sources, and found the following quantities of arsenic²:—

	Per cent.
Dust from shelves, Mr. Fairley's laboratory . . .	0.010
„ „ Mr. Mackey's „ . . .	0.011
Dust from bookcase, Mr. Fairley's office . . .	0.006
„ shop, Commercial Street, Leeds . . .	0.004

We have been able to confirm Mr. Fairley's result in two specimens of dust, one taken from the top of a book-shelf near station 5 (Headingley), which contained a trace, and the other collected in the University (station 7), which consisted largely of soot, and contained 0.015 per cent.

There can be little doubt that the arsenic in the dust was present in the smuts from the coal.

Mr. Delépine,³ in his evidence before the above Royal Commission, gave results of his examination of soot from various coals. In soot from South Yorkshire coals he found 0.08 per cent. of As_2O_3 ; in the soot from a coke stove burning coke from the Manchester gasworks, 0.4 per cent. was present; in another soot from coke, about 0.5 per cent. He concluded that “the large amount of arsenic in soot causes a marked arsenical contamination of the air in Manchester, and may

¹ “Report of the Royal Commission on Arsenical Poisoning,” Part I., 1901; Part II., 1902-3.

² *Ibid.*, Part II., p. 62.

³ *Ibid.*, Part I., p. 195.

account for the bad effects of this air on vegetation." Further on he said, "I have a suspicion that soot from towns, where arsenical coal is used, is far more irritating to the lungs than pure coal dust. The reason why I say so is that I have noticed there is generally more fibrous tissue produced in the lung in town anthracosis than when the coal is inhaled as dust, as, for instance, in the case of coal-miners. I find the lungs of coal-miners may become as black as soot and all the lymphatic vessels entirely distended with ordinary coal dust without there being evidence of very distinct inflammatory reaction; whilst, on the contrary, in towns, where the amount of carbon collected in the lungs is smaller, there are frequently capsules of fibrous tissue in the lungs around small masses of carbon which have accumulated, indicating some irritating action on the part of the soot."

A large number of samples of soot have been examined by us for arsenic, which was found to be present in every case.¹ The following are the results calculated as As_2O_3 :—

	10 ft.	15 ft.	20 ft.	25 ft.	30 ft.	35 ft.
Winston Gardens .	0·0021	0·0044	0·0056	0·0090	0·0053	0·0017

It is seen from these figures that the quantity increases to a maximum at 25 ft. from the fire-grate and then diminishes. The result is what might be anticipated from the fact that arsenic readily sublimes both in the elementary state and as oxide, and would therefore pass from the hotter to the cooler part of the flue where the greater portion would deposit.

The same result was obtained in the case of soot collected at different heights from the boiler chimney of the Leeds University (per cent. of As_2O_3)—

	Coal.	Bottom of chimney.	3 ft.	13 ft.	Top of chimney, 100 ft.
University chimney .	0·129	0·104	0·073	0·100	0·160

The cause of the increase in the amount of arsenic at the bottom of the chimney is not apparent, but it may possibly be due to local cooling. It is, however, noteworthy that the highest figure is obtained at the point where the soot escapes into the

¹ These analyses were performed by the Gutzeit method under our supervision by Mr. C. J. Smithells, a student of the Leeds University, to whom we offer our best thanks.

open air, and that the percentage is higher than in the coal used. It should be noticed, also, that the lower quality of coal used for the boilers is higher in its arsenic content.

Finally, the amount of arsenic has been estimated in a good quality of Yorkshire coal used for domestic purposes in which only a trace of arsenic was present. The soot in this case, collected near the bottom of the flue, contained 0.018 per cent.

It is an interesting fact that all town dust, as well as town air contaminated with soot, is never free from arsenic, and, according to Mr. Delépine, may affect detrimentally the health of the community.

TOWN FOG

Fog or mist consists of suspended particles of water. One curious and interesting feature about the formation of fine particles of mist or the larger particles we call raindrops or dew is that the starting-point, the nucleus of each of these particles of water, is a speck of dust—a speck which may be so minute as to be invisible to the naked eye. Particles of water may also be deposited on what are known as ions; but this is an artificial condition of the air, which may be induced by radioactive substances and in other ways. Generally speaking, however, suspended particles of water in the air have a solid nucleus. Without dust there is no mist, rain, or dew. What would happen, then, if air free from dust were saturated with moisture and the temperature fell? Water would be deposited, but only on solid objects. It would appear on the ground and on buildings. It would stream down the walls of our houses and soak the surface of the earth. Every solid thing out-of-doors would be wet, but no mist would appear and no rain would fall. As the number of these dust particles have a direct relation to the density of a fog, determinations have been made of the number in the air of Leeds at different centres on the same day by the use of an ingenious apparatus devised by Mr. John Aitken, F.R.S., and known as “Aitken’s dust counter.”

Dust Particles in Leeds Air.

Station No.	Locality.	Number per cubic inch.
7	Woodhouse Moor (N.W. wind)	530,000
4-7	The University	852,000
4	Town Hall Square	1,238,000
2-4	Parish Churchyard	3,638,000
—	Glasgow (N.W. wind, Aitken)	3,736,000

The formation of mist or fog is necessarily connected with fall of temperature, but this fall may have a different origin in different cases. One well-recognized cause of fog formation is cooling of the air near the ground by radiation at the surface; but there is another and frequent cause, as one of us has shown,¹ namely, by contact of a descending flow from higher ground of cool air coming in contact with a warm, saturated layer lying above a moist surface, and may be called, in contradistinction to "radiation or cold-surface fog," a "contact fog." Again, a fog formed in one locality may drift into another, and this form has been termed a "cloud fog." To these three classes Mr. Lempfert, of the Meteorological Department, has added a fourth, or "smoke fog," which is caused by an accumulation of products of combustion in the atmosphere of large towns in dry, calm weather, so as to produce the appearance of fog.² According to this observer, the phenomenon known as "high fog," where the fog is confined to an area some distance above the level of the ground, can also occur under a variety of circumstances.

Of the 39 fogs recorded in London from September 1, 1902, to March 31, 1903, 27 were radiation and contact fogs, 4 were cloud fogs, and 8 were smoke fogs, that is, 20 per cent. of London fogs were artificially induced and preventible.

Without discussing at greater length the cause or character of fogs, let us turn to the effects of a town fog.

Fog is usually accompanied by a high barometer, a calm atmosphere, and a fall of temperature. Under these conditions a film of water coats every little floating particle of dust, which, heavily weighted with its unwonted cloak of moisture, has its progress impeded, hangs or falls, but does not rise, and, in its turn, impedes the movement of the air. Stagnation of the atmosphere is produced, and there occurs an accumulation of products of combustion, namely, carbonic acid, sulphurous and sulphuric acid, and soot, which under ordinary conditions

¹ J. B. Cohen, "One Cause of Mist Formation," *Quart. Journ. Roy. Met. Soc.*, vol. xxx., p. 211.

² A very complete account of the character and frequency of London fogs is given by Mr. R. G. K. Lempfert, of the Meteorological Department (see Blue Book, 1904, No. 160, on London Fogs), and by Captain A. Carpenter, R.N., on London Fog Inquiry, 1903.

are to some extent dispersed. Our senses give us abundant evidence of soot and sulphurous acid. Our faces and clothes are soon begrimed, and eyes and throats suffer from the irritating effects of the acid. The increase of carbonic acid in London air during fog has been determined by Dr. W. J. Russell,¹ who made frequent observations throughout the years 1882 and 1883. Taking 3·5 parts per 100,000 as the maximum amount of carbon dioxide in pure country air, the following results were recorded during mist and fog:—

Date 1882.	Weather.	Vols. of CO ₂ in 10,000 air.	Temperature C.		Barometer mm.	Direction of wind.
			Wet bulb.	Dry bulb.		
Jan. 17	Dense black fog . . .	6·7	—	10·0	786	S.
" 18	" " " " . . .	5·7	—	4·0	786	S.
" 19	Slight white fog . . .	4·8	—	6·0	768	S.
" 25	Dense black fog . . .	10·5	—	3·5	780	S.
Feb. 3	Slight fog . . .	6·9	3·0	4·4	781	S.
" 4	Dense black fog . . .	10·7	4·0	5·0	785	S.
Mar. 15	Slight white fog . . .	5·6	9·0	11·0	775	S.E.
Oct. 26	White fog . . .	9·9	0·6	7·7	750	W.
Nov. 18	Dense black fog . . .	9·6	2·2	2·7	760	S.E.
Dec. 1	Thick white fog . . .	5·5	1·6	2·2	765	S.
" 2	Slight mist . . .	5·1	1·1	1·6	766	S.E.
" 10	Thick white fog . . .	9·4	0·5	1·1	755	S.W.
" 11	" " " (noon) .	11·0	0·0	0·5	755	S.W.
" 11	" " " (5 p.m.)	14·1	0·0	0·5	755	S.W.
" 14	White fog, slight . . .	6·2	4·4	4·4	755	S.E.
" 15	" " " . . .	5·4	5·0	6·1	753	S.E.
" 15	Overhead fog, white . .	4·8	3·3	4·4	760	S.E.
" 20	Dense black fog . . .	8·1	4·4	4·7	767	S.

"The largest amount of carbonic acid found was 14·1 parts; this was on December 11, 1882, and was during a long-continued fog. On referring to the table it will be seen that the fog had begun on the previous day, when there was a 'thick white fog,' and the carbonic acid had then increased to 9·4; at noon on the 11th there were 11·0 parts, and at 5 p.m. the carbonic acid had increased to 14·1 in 10,000 of air, that is, there was more than 3½ times the normal amount present. Supposing, then, this had been an increase of only pure carbonic acid, such a change in composition of the atmosphere would be felt by most people, but an accumulation of carbonic acid

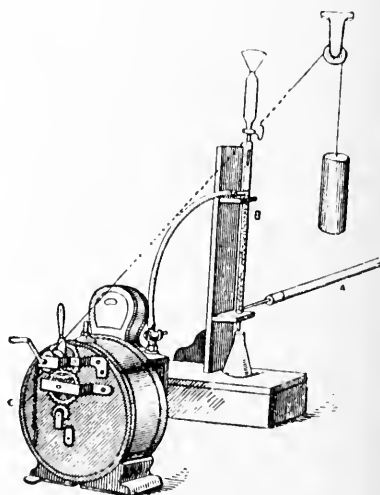
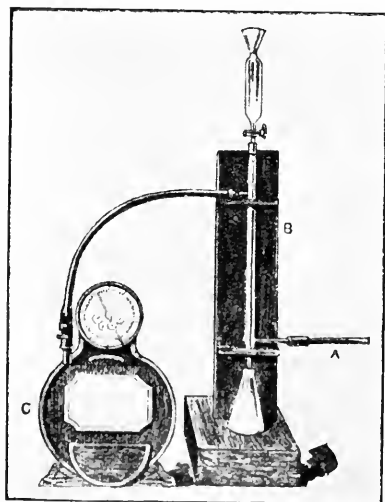
¹ Monthly Weather Report of the Meteorological Office for April, 1884.

means, certainly, a very large accumulation of other bodies, which probably are more, rather than less, deleterious than carbonic acid itself."

This statement, which Dr. Russell has appended to his observations, is entirely supported by the results of experiments on sulphurous acid found in town air during fog.

Before, however, referring to the other and more deleterious accompaniments of fog, the following data of the amount of carbonic acid in the air obtained by Dr. Russell shows how rapidly the air assumes its normal condition when the fog clears:—

	Vols. of CO ₂ per 100,000 air during fog.	Vols. of CO ₂ per 100,000 after fog had cleared.
1884.		
Oct. 26 . . .	9.9	5.0 after 2 hours
Nov. 18 . . .	9.6	5.0 " 1½ "
Dec. 1 . . .	5.5	4.1 " 4½ "
Dec. 20 . . .	8.1	5.2 " 1½ "
1884.		
Oct. 11 . . .	7.6	5.1 " 5 "
April 27 . . .	5.3	4.6 " 2½ "



FIGS. 32, 33.—Apparatus for estimating sulphurous acid in air.

The apparatus for estimating sulphurous acid in air, which was devised by one of us in connection with experiments

instituted in Manchester in 1891 on behalf of the "Air Analysis Committee" of the Manchester Field Naturalists' Society, is shown in the above Figs. 32, 33. It consists of a long glass tube, A (about $\frac{1}{2}$ inch in diameter, open at both ends), which is fixed horizontally so as to project into the open air and a glass tower, B, about 30 inches high and $1\frac{1}{4}$ inches in diameter, open at the top and drawn out into a fine jet at the bottom. Two side tubes are fixed to the tower, one near the bottom and the other on the opposite side near the top. The tower is filled to within 1 inch of the upper side-piece with glass beads, and into the open top a tap-funnel is inserted through a tightly fitting cork. The lower side tube is attached to the horizontal tube; the upper one, by means of a wide indiarubber tubing, to a combined meter and aspirator, C. This is an ordinary wet meter converted into an aspirator by attaching toothed wheels to the revolving drum, and driving the wheels by means of a wire cord passing over a pulley and carrying a weight. A series of dials register the volume to $\frac{1}{100}$ th of a cubic foot. The method of conducting the experiment is as follows: About 250 c.c. of a solution of hydrogen peroxide in water containing about 1 mgrm. of active oxygen in each c.c. is poured into the tap-funnel, from which it is allowed to drop on to the glass beads at the rate of about 1 drop a second. The liquid passes down and out at the constricted end of the tube and falls into a flask placed below. A drop of liquid permanently fills the jet and seals it effectually from the entrance of air from the interior of the room. After running through, the liquid is poured back into the funnel and passed through again. The weight being wound up, the volume indicated on the dial is read off and the drum set in motion. With a column of beads of about 20 ins. and a weight of 20 lbs., 20 cubic feet can be aspirated in an hour. Once started the apparatus needs no further supervision until either the weight has reached the ground or the solution of hydrogen peroxide has run out of the funnel. The period required for this is readily determined, so that no time is lost in looking after the apparatus.

The following tables contain the results of numerous observations of the sulphurous acid in the air. The first gives the average amount of sulphurous acid in Manchester air during

four months of 1892, and the second the amount in the outskirts and centre of the town.

Sulphurous Acid in Manchester Air.

Milligrams of SO_3 per 100 cubic feet.

Month.	Minimum.	Maximum.	Average.
September	0·7	3·5	1·2
October	0·7	6·0	2·4
November	2·0	12·0	6·8
December	3·0	30·0	6·10

Milligrams of SO_3 per 100 cubic feet.

Date.	Outskirts.	Centre.
September 5	0·7	1·8
October 14	0·8	3·5
November 5	1·7	4·9
„ 10	2·5	4·1
„ 13	3·3	7·6
„ 17	2·0	5·9
„ 19	2·9	8·4
„ 22 Fog	4·2	9·7
„ 27 Fog	9·3	15·7
December 17	2·3	9·2
„ 21 Fog	16·5	32·2
„ 22 Fog	12·7	22·6
„ 23 Fog	12·7	25·8

Thus we see that both carbonic acid and sulphurous acid, as might be anticipated, rapidly increase during fog. That the amount of soot increases *pari passu* scarcely requires proof. The condition of one's face and clothes and household fabrics during dense fog, and the black, slimy deposit which is seen to cover the ground after the air has cleared, are sufficient evidence of this accumulation. An attempt to estimate this deposit by collecting it on glass plates was frustrated by the fortunate absence of fogs in Leeds since October, 1909, when the plate experiments were in progress (see p. 17).

On January 27, 1909, there was, however, a dense fog, accompanied by a heavy deposit of hoar frost. A large amount of the latter was collected in the neighbourhood of station 5, melted, and analysed. To compare the amount of impurity with that of normal rain, the average composition of rain of the year, which fell at the same station, is given in the following table:—

Rain and Hoar Frost at Station 5 (Headingley).

Parts per million.

	Suspended matter.	Tar.	Ash.	Acidity.	Sulphur			Chlorine.	Nitrogen		
					as SO ₃ .	as SO ₂ .	Total.		as NH ₃ .	as N ₂ O ₅ .	as albuminoid.
Average rain }	115	15	28	1.9	22	5.7	27.7	7.3	1.98	0.196	0.434
Hoar Frost }	4620	158	67	102.9	148	41.0	18.9	94.6	8.57	0.0	1.618

The hoar frost contained forty times as much soot as the average rain, and one hundred times the acidity. The photograph (Fig. 34) gives the appearance of (I) rain-water, (II) melted snow before the fog set in, (III) melted snow after the fog dispersed.

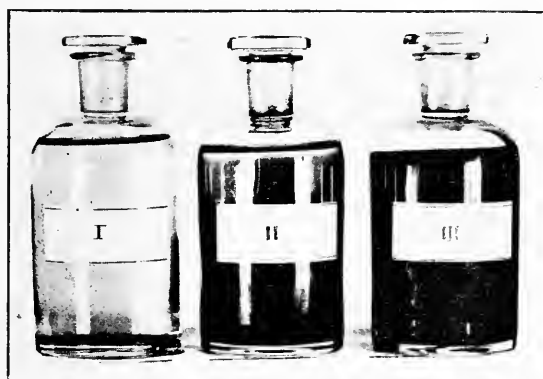


FIG. 34.—Appearance of (I) rain-water, (II) melted snow before fog, and (III) after fog.

There is another record of some interest which may be quoted here. "During the last fortnight in February, 1891, the previously washed roofs of the glass-houses at Chelsea and Kew, the former just within and the latter just outside London, received a deposit from the fog amounting to 6 tons to the

square mile,"¹ or eight times the average daily deposit in Leeds. This soot had the following composition :—

Substance.	Chelsea.	Kew.
	Per cent.	Per cent.
Carbon	39·0	42·5
Hydrocarbons	12·3	4·8
Organic bases	2·0	—
Sulphuric acid	4·3	4·0
Hydrochloric acid	1·4	0·8
Ammonia	1·4	1·1
Mineral matter	23·8	41·5
Water (by difference)	5·8	5·3

Even in a country district like Garforth, which is subject to some atmospheric contamination from a neighbouring colliery as well as from the more distant smoke of Leeds, a considerable increase in the impurities occurs in time of fog. The following statistics have been selected from the analyses of Garforth rain during the winter of 1908–1909 on dates when fogs occurred, and for comparison the average impurities for the two years 1907–1909 are given on the last line of the table.

Influence of Fog—Analysis of Garforth Rain.

Parts per million.

Date.	Nitrogen			Total.	Cl.	SO ₃ .	SO ₂ .	Acidity as H ₂ SO ₄ .
	as NH ₃ .	as N ₂ O ₅	as albu- minoid.					
1908.								
Oct. 21 . . .	2·462	0	0·865	3·327	1·33	17·18	7·79	15·80
Nov. . . .	3·214	0	0·276	3·490	6·14	19·47	6·64	7·97
Dec. . . .	4·178	0	1·236	5·414	11·12	29·08	6·64	41·37
Dec. . . .	2·472	0	0·096	2·568	5·88	16·26	0·0	11·16
1909.								
Jan. . . .	1·186	0·528	0·536	2·250	21·75	10·66	4·68	4·40
Average 1907-09	1·10	0·33	0·24	1·67	3·38	11·43	3·48	3·49

Dr. Russell² has estimated the solid organic impurities in

¹ Hon. R. Russell, *London Fog and Smoke*.

² "On the Impurities in London Air," *The Monthly Weather Report of the Meteorological Office for August, 1885*.

the air during fine, dull, and foggy weather in 1883 to 1885, and, although no experiments were made in dense fog, the results are sufficiently suggestive, the average amount in 1000 cubic feet of air being as follows :—

		Grams per 1000 cubic feet of air.
Fine weather	0.0035
Dull ,,	0.0103
Foggy ,,	0.0244

from which it is seen that with only slight fog the amount of soot increases seven times. If the ratio increases with that of the other products of combustion (carbonic and sulphurous acid), it would be four times as compared with the carbonic acid and fourteen times as compared with the sulphurous acid. It must be remembered, however, that these two products are gaseous and therefore diffuse, and moreover that the sulphurous acid is much more soluble in water than the carbonic acid, which will explain the larger increase of the former. That the increase in the amount of soot must necessarily be much greater than that of the sulphurous acid follows from the fact that being solid it cannot escape by diffusion. There is one other point to be considered. If we assume dust particles to form the solid nucleus upon which the moisture is precipitated, then it might be supposed, from the denseness of fog depending upon the number of these particles, that the fog must be thicker in the town than in the country. The very large number of these particles distributed everywhere, even over the sea, is, however, more than sufficient to produce the densest fog, and according to the Hon. Rollo Russell,¹ the dense fogs of towns cannot be ascribed to this cause. But each particle of water floating as fog becomes coated with a film of sooty tar. Evaporation is thus retarded, and a fog once formed is liable to persist longer than if these particles were composed of pure water. The black surface of each particle of water will lose heat more quickly than a correspondingly clean particle, and also help to retard its dispersion. Whether, as sometimes alleged, smoke may actually originate, as well as aggravate, a fog is still an open question; but the evidence seems on the whole to be opposed to this idea.²

¹ *London Fog and Smoke*. London: P. S. King & Son. 1905.

² Dr. W. N. Shaw, Address on Fog, Coal Smoke Abatement Conference 1905.

The blackening of silver and copper articles, which is so noticeable during foggy weather in town, is due to a thin film of the black sulphide of the two metals; but is not produced by either sulphurous or sulphuric acid. It may, however, be caused by sulphur disseminated as sulphide in the soot, or by hydrogen sulphide contained in the products of combustion of coal. In order to ascertain the amount of sulphur in soot, we have estimated the quantity in the various samples referred to on p. 7 with the following results:—

Percentage of Sulphur in Soot.

Source of sample.	Base of chimney.	Top of chimney.
Soot from brass foundry	2·23	4·36
North Grange Mount, study flue . .	2·32	—
kitchen	1·46	—
The University, fireplace	2·99	—
boiler	2·76	2·84
Winston Gardens, dining-room . .	2·18	2·45
kitchen	2·20	—

THE DISPERSAL OF SOOT

It would be an interesting point to discover to what extent outlying districts participate in the atmospheric contamination produced in an industrial centre. It is an easy matter to detect the presence of soot at a distance of many miles from its origin, though the quantity falls away rapidly, and it will probably only be the finest particles which travel any distance. That such particles may travel as much as 60 miles is proved by the deposition of salt crystals observed by one of us in the neighbourhood of Leeds after a strong south-westerly gale. These salt crystals could only have been deposited from spray blown across from the Irish Channel. But there is another way in which soot is conveyed long distances, namely, by rain-clouds traversing an industrial area and absorbing, like fog, the solid and gaseous products of combustion. Where the cloud discharges a very visible fall of soot occurs. This phenomenon is not by any means uncommon. In the Lake District such deposits brought down by rain are frequently observed. A rain cloud charged with soot, when it breaks above a sheet of water, produces a characteristic chequered appearance on

the surface, which is due to the tarry matter spreading out into patches. When the rain ceases these black greasy patches are blown shorewards and form a fringe of black scum (Fig. 35). An examination of this scum clearly reveals its origin. The



FIG. 35.—Black fringe of soot on Coniston Lake; Lake District.

same thing has been noticed on snow on the hills of the district, especially when on the melting of the snow the black particles collect, leaving dark patches of soot on the grass. Putting the facts together, it may safely be inferred that nowhere, at least in the north of England, is the country free from atmospheric contamination from smoke.

APPENDIX A

The Influence of Coal-smoke upon Health

By DR. ASCHER, DISTRICT MEDICAL OFFICER FOR HAMM,
WESTPHALIA.

On account of the low death-rate from tuberculosis amongst coal-miners it was believed that coal-dust, smoke, and soot were beneficial to health. The following Table I. shows that this view is incorrect :—

Fifty-fifth Annual Report of the Registrar-General of the United Kingdom.

TABLE I.

	Death rate per 10,000.	
	T.	NT.
Labourers in agricultural districts . . .	18·8	18·6
Coal-miners ¹	14·0	32·6
Chimney sweeps and soot merchants . .	37·1	43·1
Coal heavers	29·7	65·6

T = death rate from tuberculosis.

NT = death rate from lung diseases which are non-tubercular.

Whilst the death-rate from tuberculosis is only small amongst coal-miners, it is not so among others working in coal-dust, smoke, and soot. The reason is that coal-miners are a hardy race, living in good social conditions. More important is the fact that the death-rate from non-tubercular lung diseases is higher than among workmen living in the country. The same is the case in Germany.

TABLE II.

	T.	NT.
Workmen in Prussia, 15-60 years . . .	28.8	16.5
Coal-miners in the Ruhr district . . .	13.1	39.2

Here again the low death-rate from tuberculosis among the coal-miners is due to the fact that they are very robust and earn high wages. The high death-rate from non-tubercular lung disease is again very striking. According to Russell the following number of persons per 100,000 died in and near Glasgow in 1880:—

TABLE III.

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Rural districts	289	354	996	1639
City of Glasgow	773	1024	1232	3029
Thinly populated part of Glasgow, 36 persons per acre	450	600	870	1920
Densely populated part of Glasgow, 512 persons per acre	1020	1860	1600	4480

The death-rate in different parts of Manchester per 100,000 for the year ending the third quarter of 1891 was as follows:—

TABLE IV.

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Thinly populated part	241	534	954	1729
Thickly „ „ (Ancoats) . . .	510	1544	1798	3752

The death rate per 100,000 for the year ending the fourth quarter of 1892 was—

	Contagious diseases.	Lung diseases.	Other diseases.	Total.
Thinly populated part	175	429	904	1508
Thickly „ „ (Ancoats) . . .	455	1166	1630	3251

“In the above (Tables III. and IV.) phthisis is included among the ‘lung diseases’; otherwise the difference would have been much greater.”

The higher death-rate from lung diseases in the more densely inhabited parts of the town cannot, therefore, be ascribed to more frequent contagion.

Still more marked is the contrast between acute lung diseases and contagious diseases among those who are most subject to them, namely, children under 1 year.

TABLE V.

1876-1901.

Death-rate per 1000 under one year.

	NT.	Scarlet fever, measles, German measles, diphtheria and croup.
In six rural districts of Prussia . . .	4·3	29·8
In six industrial districts of Rhineland .	12·6	5·2

Table V. proves that the higher death-rate from non-tubercular lung diseases in the Rhenish districts is not due to worse economical conditions or a more unfavourable climate; for the six districts of East Prussia (Fischhausen, Königsberg, Labiau, Goldap, Lyck, and Oletzko) have a considerably poorer population than the six industrial districts of Rhineland (Mühlheim, Ruhr, Essen, Düsseldorf, Crefeld, Aachen, and Saarbrücken). The former have also a longer and harder winter, and a climate subject to great variations of temperature, whilst the six Rhenish districts have a mild and even temperature. Again, in the administrative area of Arnsberg, in Prussia, where there are large industrial centres, the following comparison has been made:—

TABLE VI.

1898-1907. *Death rate per 10,000.*

Non-industrial area.			Industrial area.		
	NT.	T.		NT.	T.
Arnsberg . .	28·19	23·59	Dortmund . .	36·88	14·99
Meschede . .	26·99	27·35	Bochum . .	35·89	13·78
Bilron . . .	24·50	29·36	Gelsenkirchen .	37·35	15·20

The three industrial districts are wealthier, and therefore have a lower death-rate from tuberculosis, but they also have a smokier

atmosphere, and therefore a higher death-rate from non-tubercular lung diseases.

Finally, we will compare two equally large towns which are situated at no great distance from one another in the industrial district of Westphalia, which are built in the same style, and differ only in the amount of coal-smoke in the air, namely, Hamm and Gelsenkirchen. Hamm, being situated on the east fringe, receives coal-smoke only from the west; Gelsenkirchen, being in the centre, has an atmosphere constantly charged with smoke.

TABLE VII.
1900-1902. *Death-rate per 10,000.*

Classified according to age.	Hamm (east border). 32,435 pop. 30·6 NT	Gelsenkirchen (centre). 37,834 pop. 57·4 NT.
0-1 years	228·9	258·9
1-5 „	57·1	131·1
5-10 „	6·5	17·3
10-15 „	1·8	2·6
15-60 „	10·7	34·7
60 and over	140·4	210·2

We see from this table that coal-smoke increases the death-rate from acute non-tubercular lung diseases in all stages of life. This is also the reason why the death-rate from such diseases is higher in Rhenish Westphalia and in Upper Silesia, as seen from the following Table VIII. :—

TABLE VIII.
1905-1909.

	Death-rate per 10,000.
Death-rate from acute lung diseases in all German towns with 15,000 population or more.	24·0
In equally large towns of Rhenish Westphalian industrial area	34·0
In the industrial districts of Upper Silesia	36·0

A similar result is found in England if the urban and rural districts are compared.

TABLE IX.

Urban Registration Counties.			Rural Registration Counties.		
	Death-rate per 10,000.			Death-rate per 10,000.	
Glamorgan	27	1903-04	Buckingham	16	1902-04
Lancaster	29	1902-04	Cambridge	19	"
London	24	"	Cornwall	20	"
Middlesex	19	"	Hereford	18	"
Monmouth	27	"	Huntingdon	16	"
Northumberland . .	25	"	Lincoln	19	"
Nottingham	27	"	North Wales	—	"
Stafford	25	"	Norfolk	19	"
Warwick	23	"	Oxford	17	"
East Riding	24	"	Rutland	22	"
West Riding	20	"	Somersetshire	17	"
Average	26·5		Westmoreland	11	"
			Suffolk	16	"
			Wilts.	17	"
				17·5	

Taking the results of Tables I. to IX., there can be little doubt that coal-dust, smoke, and soot increase the death-rate from acute lung diseases.

APPENDIX B

Analyses and Manurial Value of Soot

THE dried sample of soot was first extracted with ether in a Soxhlet extractor, the ether soluble material being looked upon as tar.

Carbon and hydrogen were then estimated in the ether insoluble residue by the ordinary combustion method, taking the precautions necessary for substances containing nitrogen, halogens,¹ and sulphur.

The incombustible matter left over from this operation was regarded as ash.

Nitrogen was determined in the dry sample by the Kjeldahl-Gunning method.

In the estimation of sulphur, the original dry soot was fused in a platinum crucible, over asbestos, with its own weight of pure calcined magnesia, and half its weight of dry sodium carbonate. When the organic matter was completely burnt, the residue was taken up with distilled water and hydrochloric acid, oxidised with bromine water, and the sulphates, thus formed, precipitated from the boiling solution with barium chloride in the ordinary way.

The acidity was determined by shaking with distilled water for half an hour in a shaking machine, filtering under pressure, and titrating the clear filtrate against standard alkali, using congo red as indicator.

Chlorine was estimated by extracting with water, as in the case of "acidity," exactly neutralising with caustic soda, and titrating against standard silver nitrate.

¹ See Cohen, *Practical Organic Chemistry*, pp. 10 and 11.

Analyses of Domestic Soot from Winston Gardens.

	Original coal.	Kitchen soot.	Dining-room.						
			0-5 ft.	5-10 ft.	10-15 ft.	15-20 ft.	20-25 ft.	25-30 ft.	30-35 ft.
Carbon	76·80	52·34	36·45	35·13	38·58	34·14	34·60	36·27	37·22
Hydrogen	4·90	3·68	3·51	3·48	3·59	3·47	3·72	3·67	3·51
Nitrogen	1·72	4·11	6·89	7·07	5·48	6·04	6·02	5·46	5·05
Ash	1·80	17·80	5·09	5·52	4·16	4·97	4·45	4·36	4·94
Tar (Ether extract)	0·88	12·46	34·87	38·11	34·91	37·2	38·17	40·94	40·38
Sulphur	0·79	2·20	2·18	3·07	2·48	2·56	2·64	3·22	2·45
Chlorine	0·25	1·35	9·07	7·37	8·43	6·41	5·53	5·07	4·96
Acidity	0·0	0·28	0·92	0·92	0·65	0·55	0·70	0·68	0·92
Arsenic (see p. 59)									

Manurial Value of Soot.

Apparent density .	0·2748	0·2048	0·1922	0·1964	0·2450	0·2313	0·2428	0·2865
No. of lbs. per bushel	22	16½	15½	15½	19½	18½	19½	23
Value per bushel .	5½d.	6½d.	6½d.	5½d.	7d.	6½d.	6½d.	7d.
Value per ton . .	£2 3 0	£3 17 0	£3 19 0	£3 16 0	£3 7 6	£3 7 6	£3 1 0	£2 16 0

Analyses of Domestic Soot from North Grange Mount, Headingley.

	Original coal.	Kitchen flue.	Study flue.
Carbon	76·47	45·91	47·15
Hydrogen	5·22	2·18	4·85
Nitrogen	1·32	2·33	5·57
Ash	2·10	27·34	20·22
Tar	0·92	10·20	15·68
Sulphur	0·99	1·46	2·32
Chlorine	0·27	4·64	6·46
Acidity	0·0	0·0	0·50
Arsenic (see p. 60)			

Manurial Value of Soot.

Apparent density . . .	0·3265	0·2363
No. of lbs. per bushel .	25½	19
Value per bushel . . .	3½d.	6½d.
Value per ton	£1 4 5	£3 2 5

Analyses of Soot from University.

	Original coal.	Domestic soot.	Boiler soot.			
			Base.	13 ft. up.	70 ft. up.	Top.
Carbon	69·30	40·50	19·24	16·66	21·80	27·00
Hydrogen	4·89	4·37	2·71	0·86	1·44	1·68
Nitrogen	1·39	4·09	0·23	0·00	1·18	1·09
Ash	8·48	18·16	73·37	75·04	66·04	61·80
Tar	1·64	25·91	0·09	0·28	0·80	1·14
Sulphur	1·74	2·99	2·76	2·07	2·58	2·84
Chlorine	0·27	5·19	0·11	0·75	1·46	1·60
Acidity	0·0	0·39	1·62	1·04	0·58	0·47
Arsenic (see p. 50)						

Manurial Value of Soot.

Apparent density	0·340	0·447	0·467	0·436	0·429
No. of lbs. per bushel	27·0	35·8	37·4	34·9	34·3
Value per bushel	8½d.	½d.	0d.	2½d.	2½d.
Value per ton	£2 6 0	2s. 6d.	nil	13s. 2d.	12s. 2d.

Analyses of Soot from Brass Foundry in Leeds. Liquid fuel used.

	Base.	Top.
Carbon	11·36	47·71
Hydrogen	1·03	2·35
Nitrogen	0·11	2·32
Ash	82·16	31·42
Tar	1·02	10·62
Sulphur	2·23	4·36
Chlorine	0·28	1·47
Acidity	0·00	0·65

Manurial Value of Soot.

Apparent density	0·7915	0·5017
No. of lbs. per bushel	63·3	40·1
Value per bushel	½d.	5½d.
Value per ton	1s. 3d.	£1 5 11

Attention has been called on p. 4 to the great outstanding differences in the composition of domestic and boiler soots, these differences being due principally to differences both in temperature and in draught. Thus, a boiler soot is characterised by the high percentage of mineral matter it contains, and by the smallness of its content of combustible matter, *i.e.* carbon and hydrogen, and

volatile products, *i.e.* tar, ammonium chloride, and ammonium sulphate. Domestic soots, on the other hand, are rich in volatile and combustible matter, and poor in ash or mineral matter. It is interesting, too, to note in the case of boiler soots, that further up the chimney where the temperature is naturally lower we get a striking increase in the percentage of carbon, tar, and ammonium chloride, and a corresponding decrease in the percentage of ash. In the case of domestic soots, however, the differences in composition as we get further from the source of combustion are not so striking and not always in the same direction as those observed in the case of boiler soots. Thus, while there is a slight tendency for the percentage of tar to increase and the percentage of ash to decrease, the amount of an easily condensible volatile product like ammonium chloride apparently reaches its maximum about ten feet from the base of the chimney, and then steadily decreases.¹

As a manure, soot is valuable principally on account of the nitrogen it contains, this nitrogen being present almost entirely in the form of ammonium chloride or ammonium sulphate. As nitrogen in this form is worth commercially about 12*s.* a unit or 6*d.* a pound, and as the nitrogen content of soot may vary from 0 to 7 per cent., it naturally follows that the commercial value of soot as a fertiliser will vary from nothing to £4 per ton. As most soot is disposed of locally at from £2 10*s.* to £3 per ton, and as no guarantees can be obtained as to its composition, the purchaser may or may not be getting value for his money. Fortunately, however, some indication of the value of soot as a fertiliser can be obtained from its density, and the lighter the soot the higher as a rule will be its nitrogen content and the greater its commercial value. A bushel of domestic soot will, as a rule contain 1 lb. of nitrogen, and approximate in value to about 6*d.*; it is, therefore, advisable to buy by the bushel rather than by the ton. Further, no genuine domestic soot should weigh more than 1 quarter to the bushel, and any sample weighing more than 28 lbs. to the bushel may be looked upon as being a boiler soot possessing little or no fertilising value.

¹ Cohen and Ruston, *Journ. Soc. Chem. Ind.*, 1911.

APPENDIX C

Analyses of Leeds Rain-water¹

FROM October, 1906, to the end of 1909 samples of rain falling on the Manor Farm, Garforth (Experimental Farm of the University of Leeds and Yorkshire Council for Agricultural Education), were periodically collected and analysed. The farm is situated some six miles due east of the city of Leeds. The prevailing winds are westerly, and hence convey much of the impurity of the Leeds atmosphere over the farm.

The outstanding feature of these Garforth results is the relatively high amount of each of the different impurities estimated.

Thus, the total number of pounds per acre² at Garforth is 9·8, as compared with 3·8 the average at Rothamsted; the average precipitation of sulphur was equivalent to 96 pounds of SO₃ at Garforth, as compared with 17 pounds at Rothamsted. The average yearly precipitation of chlorine was 21 pounds as compared with the Rothamsted average of 15 pounds, while the impure nature of the Garforth atmosphere is strikingly illustrated by the fact that free acid equivalent to no less than 20 pounds of sulphuric acid is yearly brought down by the rain.

Other points of interest are—

(a) The amount of nitrogen brought down in the course of the year is largely determined by the amount of the rain. This is clearly evident in the data given below:—

Year.	Rainfall in inches.	Nitrogen (as ammonia + nitric acid).
1907	27·1	8·45 lbs. per acre
1908	22·7	7·46 " "
1909	28·5	9·48 " "

This is also shown by the fact that while the amount of nitrogen actually present in the rain, and expressed in parts per million, is fairly uniform during the summer and winter months, the total

¹ Crowther and Ruston, *Journal of Agricultural Science*, vol. iv.

² To convert pounds per acre into tons per square mile, multiply by 2/7.

amount expressed in pounds per acre is greater during the summer months owing to the heavier rainfall.

(b) The winter rain, as at Rothamsted, was decidedly richer in chlorine than that falling during the summer months.

(c) The winter rainfall was more than twice as acid as the summer rainfall, the proportion being notably high in the months of December and January.

(d) Light rains were proportionately more concentrated than heavy rain.

(e) The impurities in the rain are to a large extent influenced by the prevailing winds, rain falling when the wind is blowing from a westerly direction over Leeds being much more impure than that accompanying a north or north-east wind, which would blow over a purely agricultural district, *e.g.*—

	Wind.	Parts per million.			
		Total N.	Cl.	SO ₃ .	Acidity.
Oct. 1-2, 1906 . .	W.	0·0917	0·85	1·59	0·465
Oct. 3, 1906 . .	N.	0·0419	0·35	1·12	0·350

(f) Notwithstanding these variations, the total amount of these impurities brought down yearly, when expressed as pounds per acre, give a fairly constant figure, the largest variation being found in the amount of free acid deposited.

The amounts of chlorine (present as chlorides) found in the yearly rainfall ranged from 27·9 tons per square mile at station 9 to 56·5 tons at station 2. Throughout the semi-industrial and non-industrial area the amount was not more than about 14 tons per square mile, with the exception of station 6, where the total reached 31 tons. This high figure finds an explanation in the salt-glazing process carried on at a neighbouring fireclay works. The excessive amount of this impurity in all the rain-water is largely due to smoke pollution, coal containing roughly 0·3 per cent. of chlorine, and soot sometimes containing as much as 9 per cent. of this substance.¹

¹ See Appendix B., p. 78.

Total Amount of Deposit in Leeds and Garforth Rain,

Tons per square mile.

Station No.	Insoluble (soot).				Sulphur compounds.				Chlorine.	Nitrogen.			
	Carbon.	Tar.	Ash.	Total.	Free acid, H ₂ SO ₄ .	As sulphate.	In other forms.	Total.		As ammonia.	As nitrate.	As albuminoid.	Total.
1	189.6	31.4	318.0	539.0	10.0	35.2	12.3	47.5	47.0	3.71	0.00	1.34	5.05
2	241.2	19.7	187.2	448.1	26.7	52.9	8.6	61.5	56.5	4.43	0.00	0.83	5.26
3	87.1	42.6	202.5	332.2	8.5	77.0	19.1	96.1	29.0	4.11	0.14	1.00	5.25
4	99.7	22.3	120.6	242.6	12.9	42.5	13.7	56.2	21.4	4.11	0.08	0.63	4.82
5	100.2	12.3	56.9	169.4	3.1	32.3	11.4	43.7	11.7	3.17	0.31	0.23	3.71
6	98.0	9.7	61.7	169.4	8.3	31.4	13.1	44.5	31.0	2.83	0.28	0.91	4.02
7	63.2	9.1	41.7	114.0	7.5	24.3	14.0	38.3	14.6	2.65	0.23	0.46	3.34
8	52.3	8.0	40.3	100.6	2.3	22.0	20.0	42.0	16.3	2.20	0.05	0.65	2.90
9	19.2	7.4	15.4	42.0	3.1	23.4	4.5	27.9	9.7	2.37	0.31	0.60	3.28
10	7.7	4.0	14.0	25.7	0.0	15.1	5.7	20.8	11.0	1.65	0.20	0.37	2.22
11	—	—	—	—	8.0	18.6	7.4	26.0	6.3	1.43	0.91	0.31	2.65

APPENDIX D

The Soot-fall of London

OBSERVATIONS on the soot-fall of London, made by Drs. H. A. des Vœux and J. S. Owens, appeared in the *Lancet* for January 6, 1912, but were unfortunately too late for insertion in their proper place in this volume. As they are of considerable interest, we have made an abstract of the principal results.

The method which they adopted was to collect rain-water, as we have done, but instead of a 12-inch funnel inserted into a bottle they used what they term a *soot-gauge* or large rectangular hopper of 4 square feet area connected with a capacious bottle. The contents of each bottle were analysed at intervals of about a month. Four stations were selected for the experiments, three in London, namely, A, Buckingham Gate, S.W.; B, Horseferry Road, S.W.; and C, Old Street, City; and a fourth, D, on the border of the metropolitan area at Sutton, Surrey.

The experiments lasted over a year, from June, 1910, to June, 1911. The following table gives the total deposit of the various ingredients for the year at the four stations:—

Annual Deposit in London Rain, 1910–1911.

	Rain 4 sq. ft.	Total deposit 4 sq. ft.	Insoluble (soot).	Dissolved solids.	Sulphate SO ₄ .	Ammonia NH ₃ .
	litres	grams	grams	grams	grams	grams
A. Buckingham Gate, S.W.	201	71·98	46·33	25·65	6·01	5·01
B. Horseferry Road, S.W.	192	60·34	33·49	26·85	5·94	5·13
C. Old Street, E.C. . .	192	92·81	60·92	31·89	10·04	7·54
D. ¹ Sutton, Surrey . .	210	27·89	8·36	19·53	0·89	0·34

¹ The November sample was lost, so that the record for Sutton is for 11 months.

Annual Deposit in London Rain, 1910-1911—continued.

	Chlorine Cl.	Lime CaO.	Insoluble per sq. mile.	Total deposit per sq. mile.	Total deposit for London.
	grams	grams	tons	tons	tons
A. Buckingham Gate, S.W.	5.70	0.87	320	500	58,500
B. Horseferry Road, S.W.	4.09	0.60	233	420	49,140
C. Old Street, E.C. . . .	4.05	1.26	426	650	76,050
D. ¹ Sutton, Surrey . . .	2.16	0.29	158	195	—

The authors found that in the City the maximum deposit occurred in October–November during local fogs; the maximum in the S.W. district fell in July–September; but it contained leaves. Without leaves it was the same as in the City. The minimum total deposit in the City was in September–October. The greatest amount of insoluble deposit (soot) fell in the City during October and on days when fogs were prevalent; the smallest in September–October. The maximum in the S.W. district was January–February, and the minimum September–October. In Sutton, the maximum was in the summer months and the minimum in January–February.

It is an interesting fact that London rain is scarcely ever acid, which the authors ascribe to the absence of foundries and chemical works. They sum up for the year the quantities of the different ingredients carried down by rain for the whole of London, taking the City as the basis, as follows: of the 76,050 tons total deposit which fell on the 117 square miles of the London area 6000 tons were present as ammonia, 8000 tons were present as sulphate, and 3000 tons as chlorides. If the S.W. metropolitan station is taken as the basis, the quantities will be 53,820 tons total deposit, 4000 tons of ammonia, 5000 tons of sulphate, and 4000 tons of chlorine in chlorides.

A comparison of the above figures with our own given on p. 83 shows on the whole a very satisfactory agreement. The annual soot deposit from Leeds rain varies from 539 tons per square mile to 25 tons; in London, from 426 tons to 158 tons, the mean for the Leeds area being 220 tons, that of the London area 260 tons, per square mile. The amount of sulphuric acid in the City area was about 69 tons per square mile, whilst in Leeds the

¹ The November sample was lost, so that the record for Sutton is for 11 months.

average for the four city stations was 65 tons per square mile. In the case of ammonia, 51 tons were deposited in the London City area, but only 4 tons in the Leeds city area. On the other hand, the chlorine in the chlorides was 26 tons in the London City area against 38 tons in Leeds city area. The chief discrepancy is in the quantity of ammonia, which in London far exceeds that of Leeds, and incidentally explains the absence of free acid in London rain.

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